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CONTENTS

DEFENCE RESEARCH TELECOMMUNICATIONS ESTABLISHMENT

Frank T. Davies
Chief Superintendent

This establishment is situated at Shirley Bay along the Ottawa River some 10 miles west of the centre of Ottawa. The area is rather more than a square mile and is contiguous with the Army Connaught Ranges, used mainly for rifle competitions. DRTE is one of seven scientific establishments of the Defence Research Board which with its HQ, Operational Research, and Liaison units, comprises the fourth Service in Canadian Defence. DRB is about 2% of the Department of National Defence in manpower and budget and DRTE is about one sixth of DRB. Three DRB establishments were originally under Army and taken over by DRB at its inception in 1947. Three other establishments originated in small groups in the Navy during World War II, DRTE growing from Section 6 of RCN Operational Intelligence Centre, which by 1944 had become inter-service by attachments from the other two Services.

The present staff numbers over 500 of whom over 100 are professional engineers or physicists. The three research laboratories are named Electronics, Communications, and Radio Physics respectively, more for convenience that as an indication of distinct and separate activities. Electronics permeates all activities and the main purpost of both basic and applied research in the three laboratories is the support of Communications, Detection, and Navigation Systems.

Space research during the past eight years has become a major activity, partly by accident due to the success of our first satellite Alouette I, made here in response to an invitation from N.A.S.A. The Canadian Government subsequently accepted a N.A.S.A. invitation to launch a series of Canadian built satellites of increasing sophistication with the primary purpose of sounding the ionosphere from above. Alouette II has completed

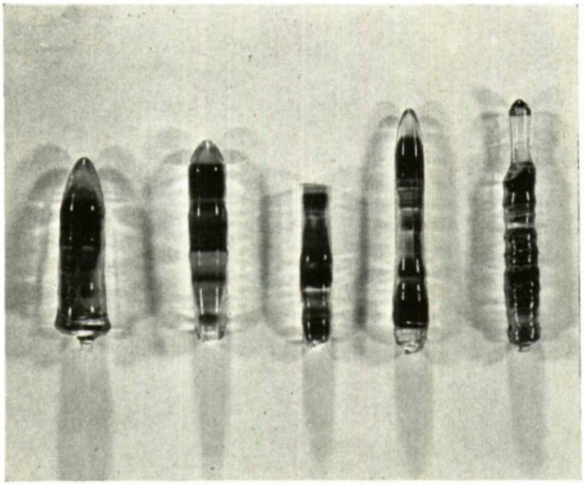
Rocket Instrumentation

Alouette II launched
29 November 1965

Satellite Communications
Research Antenna

a year in an elliptical polar orbit while Alouette I is still functioning efficiently after four years in a circular polar orbit. Subsequent satellites ISIS A, B, C (International Satellites for Ionospheric Studies) are being constructed with increasing industrial participation for launch during the next four years. Control of these satellites is maintained at DRTE as well as the major part of data processing of tapes from monitor stations. Norway, France, and Japan have set up monitors during the past year in addition to United Kingdom, United States and Canada so the programme is becoming increasingly international.

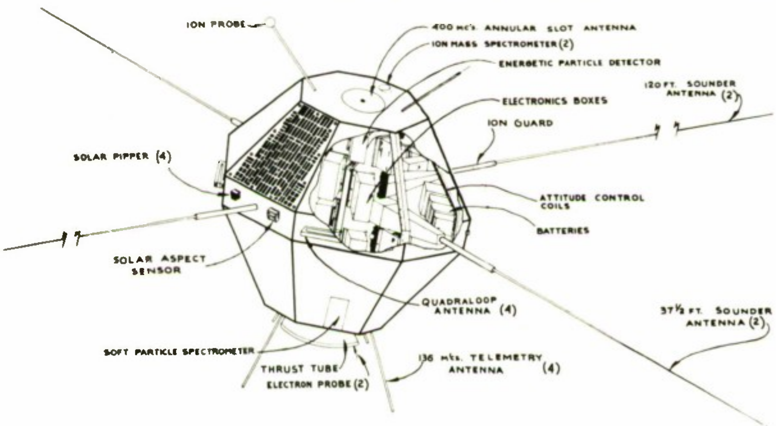
A working group which includes US and UK representatives as well as DRTE decides policy on choice of experiments and parameters of orbit. Construction is a DRTE responsibility in co-operation with Canadian Industry. The UK co-operating laboratory is Radio and Space Research Station, Slough, with whom DRTE has maintained close contact since our origins in RCN in World War II. The DRTE Trans-Atlantic oblique Sounder Experiment operated between DRTE and RSRS as well as with the Dutch Post Office at The Hague. This experiment took the guesswork out of HF propagation modes across the North Atlantic and revealed the complexity of the multipath signals structure in summer months.



Calcium Orthovanadate Crystals grown at DRTE

We have co-operated also with RAE in LF and VLF research as well as in trans-Atlantic HF/SSB tests for the past several years. This has included monitor at DRTE of VLF transmissions from UK, Norway, USA, Panama and Trinidad. RAE provided aircraft for tests of our low frequency receiver across the Atlantic, monitoring our own 80 KH_z transmissions from Ottawa.

We have had less continuous links also with other UK establishments, Norwegian Defence Research, and several US establishments. An exciting advance step occurred in the past 10 days in our Satellite Communications Programme. We have successfully communicated with a US near synchronous satellite in tests of different modulation techniques on 8 GH_z. These will continue. We are convinced that Satellite Communications will expand at economical rates considerably faster than was assumed only two or three years ago.



Isis A now under construction

Communications research and applications comprise the major activity in DRTE. Besides vertical incidence ionosondes, a net of riometers and many oblique incidence test circuits have been used to determine ionospheric characteristics over Canada. These are more intensely and more frequently disturbed than over any other country, due to the displacement of the northern magnetic poles and auroral zone towards Canada. Most of Canada is affected by this handicap to HF communications. HF is the only economical communications medium for large sparsely populated countries and we must therefore make optimum use of the ionosphere.

In recent years very considerably more knowledge of the ionosphere has been obtained from our rocket and satellite experiments, particularly the latter. A system called CHEC (Channel Evaluation and Calling) has been devised by DRTE for optimum use of available HF channels and tested in long range aircraft. Its automatic features save a great deal of operator time as well as giving assurance of message reception at the base station. Although designed for air to ground use it can also be used for other uses such as point to point ground circuits. DRTE conducts research in all parts of the radio communications spectrum as well as in visible and infra red light (lasers). Main activity at present includes adaptive systems with specific application to multiple access satellite communications, improvements in channel efficiency, detection of signals in noise, and other aspects of complete systems.

Much of this research applies to detection and navigation systems which have also been an important part of DRTE work. Support research in radio propagation, mechanical and environmental problems, solid state devices and light weight reliable subsystems is a continuing need.

A Simple System For EDDY CURRENT CRACK DETECTION For Use On Ferrous Materials

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SUMMARY

A system is described which is substantially free from spurious readings resulting from changes in the separation of the test probe and the work. It depends upon the different ways in which the probe coil impedance changes with proximity to the work, and the presence of defects. The construction of the probe, the associated circuits, and resulting performance are outlined.

Introduction

A system has been designed to indicate the presence and possible growth of cracks in a steel structure, and which has facilities for remote indication if required. It is a development of the eddy current method, which fundamentally observes the resistance of a closed circuit in the metal surface and is specifically sensitive to surface defects such as cracks which break the electrical continuity.

A coil excited by A.C. from a small oscillator is used as a test probe, and it may be wound on a magnetic core to enhance effects. Currents are induced in a metal workpiece when the probe is placed near it, thereby dissipating energy; alternatively the presence of the metal changes the electrical parameters of the coil. The conduction path in the workpiece is similar to a shorted turn on a transformer. The presence of a defect in the work underlying the coil breaks the circulating current and raises the resistance. With magnetic materials, such as steels, there are additional considerations; because of skin effect the layer in which eddy currents circulate is very thin (roughly 0·003 in. at 5 Kc/s) and the coupling of magnetic flux through the specimen is increased, but depends on the spacing of the coil and specimen. To complete the instrument a detector system is required responding to the electrical properties of the coil; sensitive to those changes due to the presence of defects but not to extraneous factors such as position of the probe. The method may be used by scanning the detecting probe over the metal surface, the response of the instrument indicating the presence of defects, or the probe may be fixed, and its response used to show the propagation of a defect beneath it.

Measuring Circuit

The method of measuring now described requires only simple circuits, and is insensitive to changes due to probe position when used on ferrous materials, so it does not require as hitherto that the probe be positioned with great accuracy. Its operation depends upon the detailed electrical behaviour of the probe. The voltage developed across the probe for a constant input current is plotted as a phase diagram in Fig. 1, for varying positions of the probe. When it is well clear of any metallic specimen its impedance is almost entirely inductive with a small resistive component from the coil winding and current feed circuit. When the probe is placed on a piece of ferrite (non-conducting magnetic material), the inductance rises as expected. When placed on steel the rise in inductance is less, but a resistive component appears as well. The locus of the voltage follows a curved path as the separation of the probe from the steel varies, and it can be shown by a theoretical argument that the locus is part of a circle. Voltage measured from the centre of this locus is independent of the position of the probe with respect to the work. If the resistance of the eddy current path is changed however, by the presence of a crack, or the use of different material the locus is different, and the voltage reading changes.

This behaviour is exploited by subtracting from the probe voltage another voltage appropriate to the centre of the locus derived from a suitable network. That shown in Fig. 2a consists of an inductor of appropriate value shunted by a variable resistor giving some adjustment, and the subtraction is accomplished by series connection to

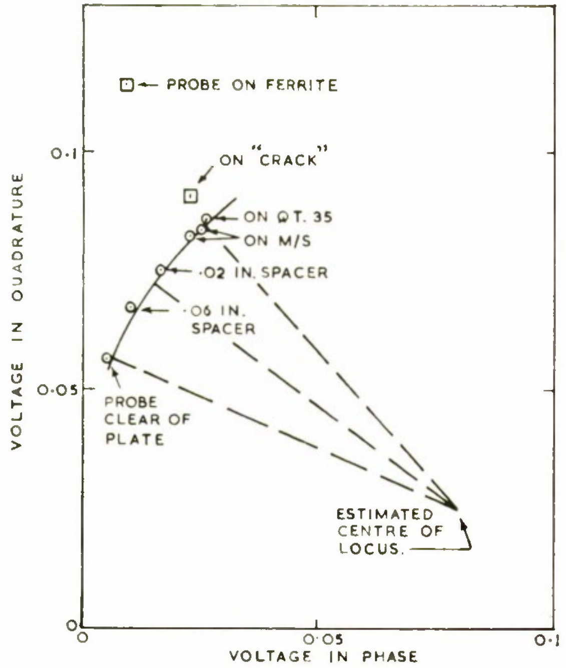
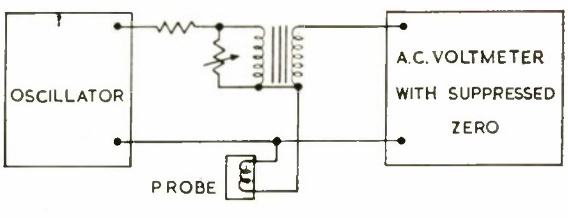
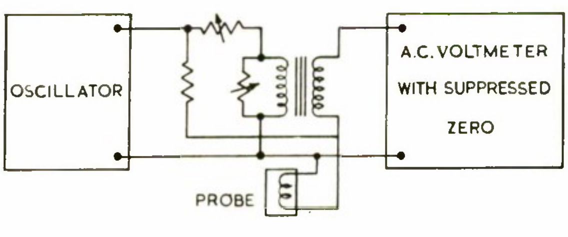


FIG. 1. Probe voltages in and out of phase, as affected by probe position and condition of test specimen.



(a)



(b)

FIG. 2. Balance networks for inductive and resistive phases.
(a) single adjustment.
(b) separate adjustments.

the probe of a secondary winding on the inductor. An alternative network giving independent adjustment of resistive and inductive components is shown in Fig. 2b. The final item of the circuit is a stable A.C. voltmeter, provided with facilities for backing off the reading to give good sensitivity in reading the relatively small changes in voltage produced by the presence of defects.

Equivalent Circuit Representation of Probe Coil

The coil system of n turns is shown diagrammatically in Fig. 3a in place near the surface of a magnetic material. Lines of alternating magnetic flux penetrate the material and an E.M.F. exists perpendicular to them. Eddy currents flow in a rather ill-defined ring shown in Fig. 3a, which is coupled magnetically to the coil winding. A magnetic flux ϕ_1, links both coil and eddy current circuits, and there is also a leakage flux ϕ_2 through the coil which fails to link with the eddy current circuit. The situation can be expressed in equivalent circuit terms as Fig. 3b, showing the coil and eddy current circuit as a transformer, of turns ratio n, with a total primary inductance $L_1 + L_2$, coupling coefficient $k = \frac{L_1}{L_1 + L_2} = \frac{\phi_1}{\phi_1 + \phi_2}$ leakage inductance L_2 and coupled inductance L_1 and R representing the eddy circuit resistance. By standard circuit theory this is expressed as the circuit of Fig. 3c for 1 : 1 turns ratio. If the separation is varied the chief effect is to increase the coupling flux ϕ_1 and thus the linked inductance L_1, but R, n^2R, and L_2 remain approximately constant. The circular impedance locus of Fig. 1 is obtained when this is further represented in terms of the series circuit Fig. 3d by the formulae:

$$L_s = L_p Q^2/(1+Q^2) \qquad R_s = n^2 R_p \;/ (1+Q^2)$$
$$(Q = n^2 R_p/\omega L_p = \omega L_s/R_s)$$

Separate coils could be used for excitation and pick-up but in the magnetic circuit such coils would be closely coupled, so that the pick-up voltage, allowing for turns ratio, would be the same as that from the exciting coil, except for the small contribution due to the coil resistance. There is therefore only a very small advantage from using separate coils, with the disadvantages of bulkier windings and extra connecting leads.

Details of Probe

For the probe a winding of 500 turns 36 s.w.g. wire was placed on the centre leg of a mu-metal core made up of cemented laminations. The ends of the core legs may be ground to fit into angles in the structure being checked. It is necessary to

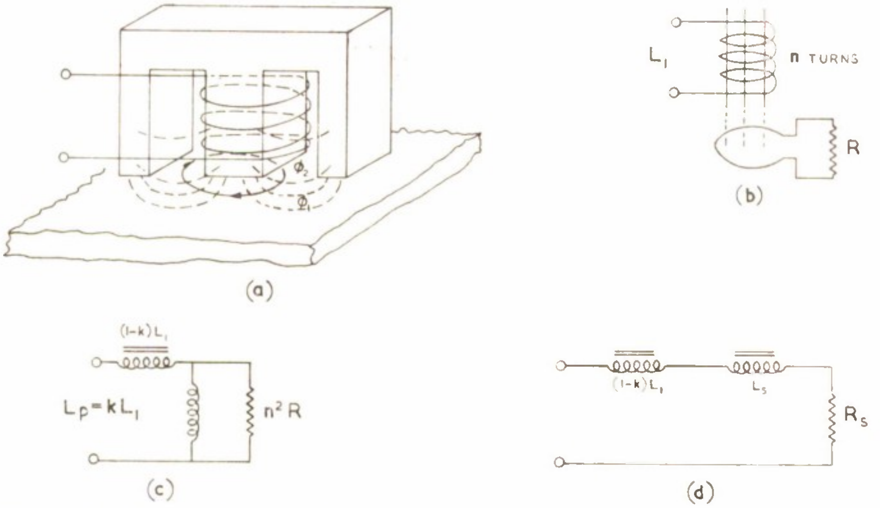


FIG. 3. Function of coil system. (a) probe arrangement and equivalent circuits, (b) transformer, (c) parallel network, (d) series network.

maintain the insulation between successive laminations in order to avoid eddy currents in the core itself. The probe was impregnated with epoxy resin in a mould giving about ½ mm resin build-up on the two outer legs to provide a locating surface with a magnetic gap. The appearance of the probe is illustrated with the general view of the equipment in Fig. 4.

A working frequency of 5 Kc/s was chosen rather arbitrarily in the early stages of the work, as providing useful effects with a coil which was easily wound. There may well be advantages from using a different frequency, but it has not yet been possible to examine the effect of frequency systematically.

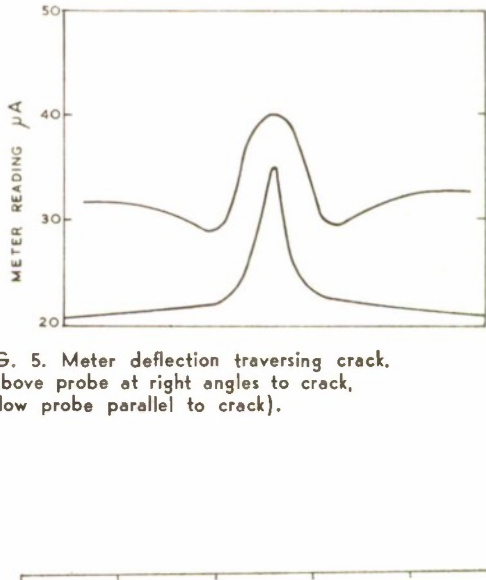


FIG. 5. Meter deflection traversing crack. (Above probe at right angles to crack, below probe parallel to crack).

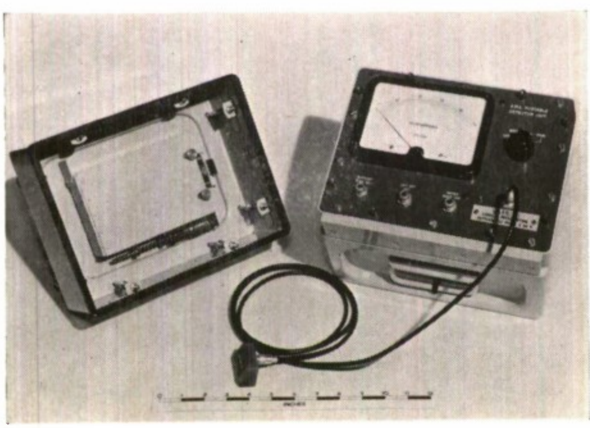


FIG. 4. One form of the equipment.

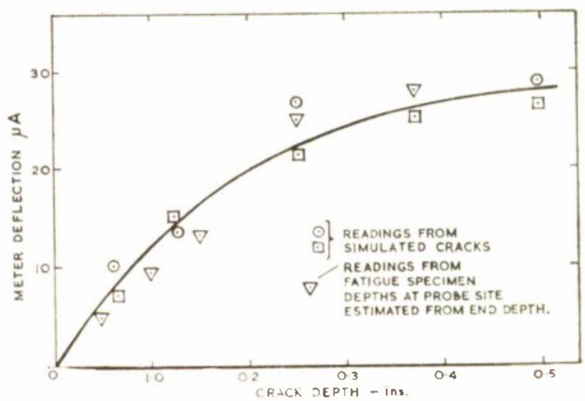


FIG. 6. Dependance of meter deflection on crack depth.

Performance

Calibrations have been made using slots cut in a flat plate to simulate cracks. The response when the probe is carried across the cut with the probe axis perpendicular and parallel respectively to the cut is shown in Fig. 5a and b. The response to varying depths of the simulated crack is shown in Fig. 6, which also includes points for a further simulated crack made by soft soldering two steel plates in a right angled configuration with thin mica sheets inserted to break electrical continuity to several known depths.

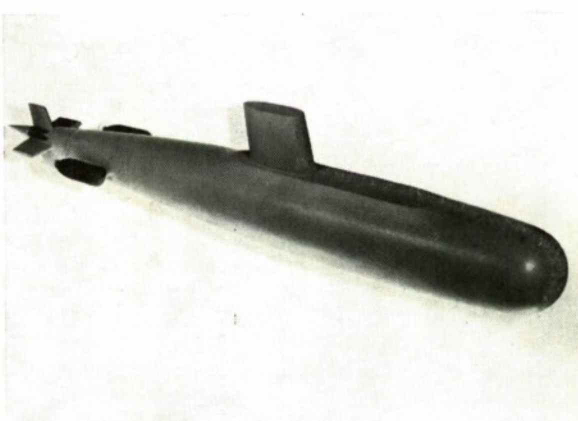
Additional calibration tests were made on a steel weld undergoing fatigue testing in a large machine and showing small cracks commencing in parts of the weld. A location for the probe was selected which showed no crack development at the commencement of the test with the probe. During the further progress of the test the eddy current meter showed large deflections which correlated with visual estimates of the crack depth at the edges of the plate.

As in other instruments, observation of real effects is limited by spurious signals, described as drift or noise. Possible sources of such signals may be identified but the interference they are likely to cause is small. The drift from the electronic circuits is negligible if appropriate circuits are used. Residual signals from probe movement only occur so far as balance is imperfect, and they too should be small. Some variation exists in the resistivity of materials other than that due to defects, for example a slightly different reading has been found between the inside and outside of a rolled mild steel bar. Such effects are not likely to be confused with correct indications from defects, and with a fixed probe monitoring crack growth the possibility of confusion is even less.

Several units have now been made as general search instruments, and in specialised form for particular applications. Results have been most encouraging in finding significant defects and further evaluation in the field is proceeding.

Acknowledgements

Many colleagues have helped at certain points of the work but particular thanks are due to Mr. R. R. Jennings (McMichael Radio), Mr. P. Christopher (N.C.R.E.), Mr. P. Wingfield and Dr. R. Warren (A.M.L.).



A model of a proposed underwater weapon system of the future. The photograph was received too late for inclusion in R. D. Wood's article published in our January issue.

MECHANISMS IN 'GUNN EFFECT' MICROWAVE OSCILLATORS

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SUMMARY

The paper, after a brief review of the physics of "Gunn effect," discusses four microwave mechanisms found in Gunn diodes: growing space charge waves giving a frequency dependent negative resistance, negative resistance due to the presence of a "domain" of high electric field, current generation by the discharging of a domain at the anode of the diode, and parametric conversion of d.c. into r.f. These mechanisms help to explain the multiplicity of modes and wide tuning range of these microwave oscillators.

Introduction

The 'Gunn effect' microwave semiconductor oscillator[1] is based on a small specimen of Gallium Arsenide to which two ohmic contacts have been made. It is made to oscillate simply by applying a voltage across the diode. The oscillations are essentially caused by negative resistivity in the semiconductor. Although Ga As is not unique in having this property it appears to be the most promising material at present.

At first sight the device is a very simple one since there are no pn junctions. This simplicity is deceptive since the mechanism of operation is quite complex with a number of different modes of oscillation[2]. The purpose of this paper is to indicate how the important modes can be explained in terms of competing microwave mechanisms.

The paper opens with a review of the necessary physics and then examines an approximate but helpful equivalent circuit for the Gunn diode to show how the relevant microwave mechanisms contribute to the various modes of oscillation. The paper concludes with speculations on the future of these devices.

Review of Gunn Effect Physics

The Gunn effect has its roots in the electronic properties of semiconductors, such as n-type Ga As, where at high enough electric fields (above 3000 V/cm for Ga As) electrons transfer[3] to higher energy, but lower mobility, states. Calculations[4] of the electrons' drift velocity in a known uniform electric field show that there is a region of negative differential mobility and hence negative differential resistivity (Fig. 1). However this negative resistivity leads to the spontaneous formation[5] of regions (domains) of very high electric field so that a simple negative resistance is not observed between the contacts of a diode. To appreciate how this break up of the electric field occurs, suppose that there is a sudden drop in the electron velocity at fields above the critical value E_c. Suppose also that there is an inhomogeneous region in the semiconductor with a higher field than the rest of the specimen. Immediately this region reaches E_c, the electrons in it will move

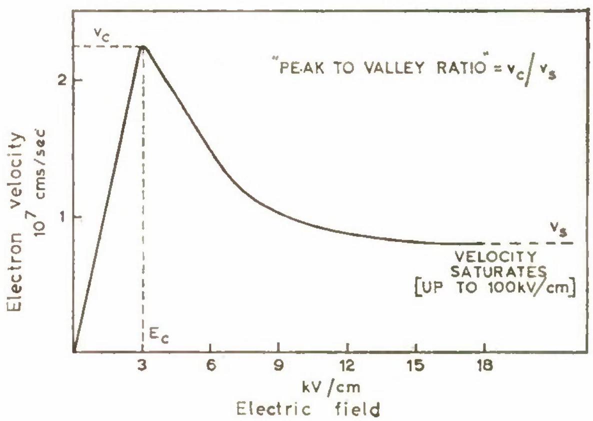


FIG. 1. Velocity-field characteristic (after Butcher).

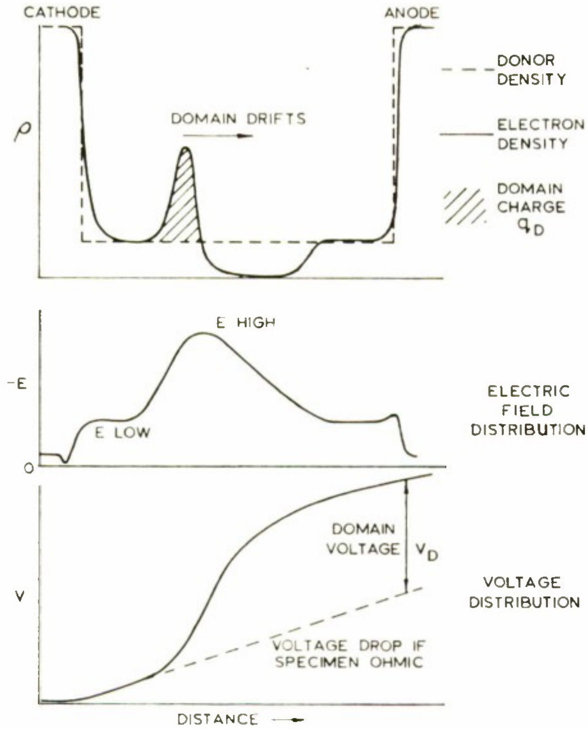


FIG. 2. Dipole domain.

slower than those outside. Electrons on the cathode side will accumulate at the rear of the region while those on the anode side will run away leaving a depletion region. The result is a dipole layer of electrons which maintains a region of high electric field[6, 7, 8, 9] (Fig. 2) and which drifts through the specimen at about 10^7 cms/sec. This is the classical Gunn domain[1] which usually forms near the cathode contact whenever the voltage across a diode rises above the critical value V_c (3 volts per 10 microns).

Other types of high field domain can exist[9] and the accumulation domain deserves special mention. The voltage across a diode can rise sufficiently fast so that the field across the whole specimen exceeds the critical value before the dipole domain has had time to form. Charge accumulates at the cathode contact and depletes in the anode contact. An accumulation of charge subsequently detaches itself from the cathode (Fig. 3) and moves through the specimen. However any inhomogeneities in the donor density are found to nucleate a depletion region ahead of the accumulation layer so that it turns into the standard dipole domain[6, 7]. Consequently if the properties of the accumulation domain are to be used they must be used in a time which is too short for dipole domains to form. Such a mode of operation is possible[10] and is discussed later.

The speed with which charge reverts to its equilibrium value inside a conductor is largely governed by the dielectric relaxation time ε/σ. Similarly in material with a negative differential conductivity $-\sigma_1$, charge builds up, as it travels along, with a time constant ε/σ_1. These relaxation times in general limit the rate of growth or decay of charge inside the diode. If the negative conductivity $-\sigma_1$ is too low and the specimen length l is too short then significant charge build up will not occur and the specimen is completely stable[6, 11]. For products $\sigma_1 l > 10^{-4}$ mhos oscillations can usually be observed though domains need not always form. The condition for domains to form needs a more detailed consideration of the growth of space charge waves in a semiconductor (such as given by Ref. 11) and indicates that $\sigma_1 l^2 > 10^{-8}$ mho cm. is the necessary sort of condition. Suitable choice of conductivity and length can yield material in which domains do not form but significant space charge wave growth will occur. It is found that this material is stable at low frequencies, with an electric field that increases towards the anode, but growing r.f. space charge waves can create negative resistance, across the diode terminals, at multiples of the charge transit time frequency[12, 13]. This negative resistance can be used for amplification or oscillation but the efficiency is low, at present, and this mechanism is not discussed further.

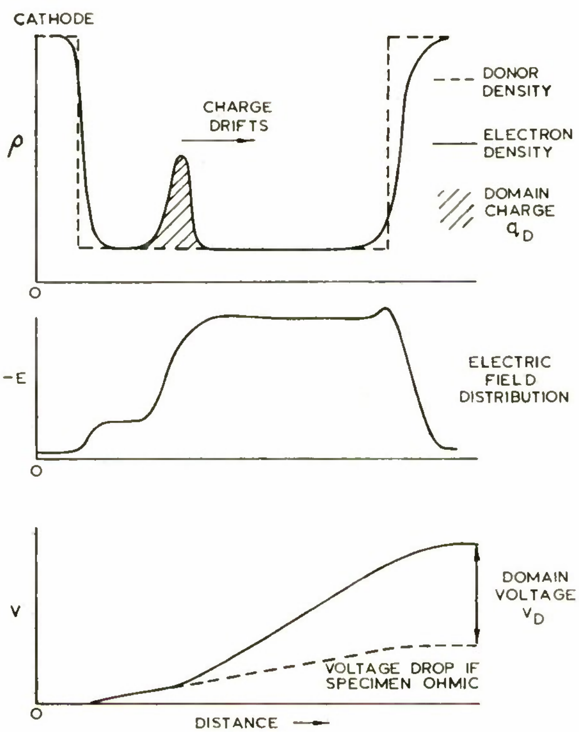


FIG. 3. Accumulation domain.

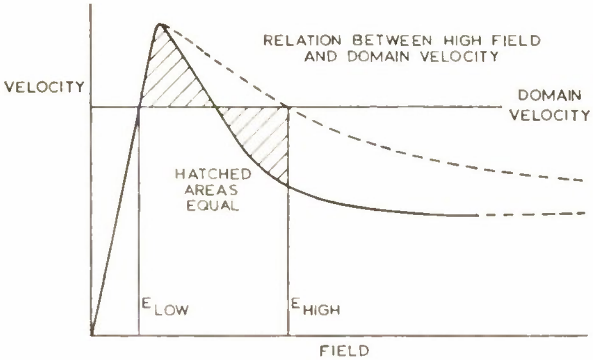
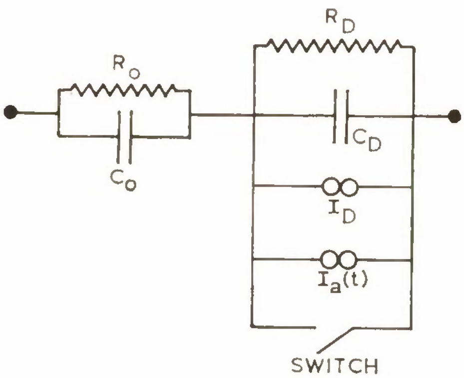
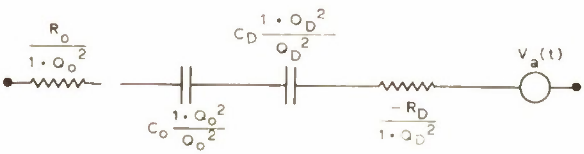


FIG. 4. Equal areas rule.



(a) Parallel form



(b) Equivalent series form at frequency ω

$$Q_o = \omega C R_o$$
$$Q_D = \omega C R_D$$
$$\left[V_a(t) \right] = \frac{I_a(t) R_D}{\sqrt{1+Q_D^2}}$$
$$R_s = \frac{R_o}{1+Q_o^2} - \frac{R_D}{1+Q_D^2}$$

FIG. 5. Equivalent circuit for Gunn diode.

Although avalanche breakdown can occur at very high electric fields or unsuitable contacts to Gallium Arsenide[14, 15], its discussion lies outside the scope of this review.

Gunn Diode Equivalent Circuit

It has been found possible to reproduce the major features of a Gunn effect oscillator by building an equivalent circuit based on Fig. 5. The essential features are the low electric field sample resistance R_o together with the domain capacity C_D which can be switched in or out of the circuit at appropriate times. This section indicates how the equivalent circuit is deduced.

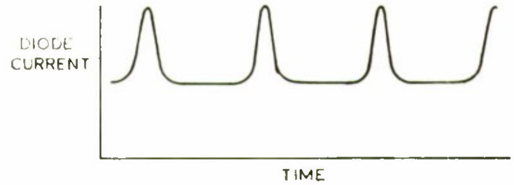
Associated with a dipole domain (Fig. 2) there is a voltage V_D in excess of the value calculated from the low field ohmic properties of the sample. There is also a domain charge q_D with a positive and negative layer similar to a capacity. This is the basis of the domain capacity C_D. Current flows through the semiconductor to charge up the domain but even if the domain charge is constant a current still flows because of the drift of the domain towards the anode. Consequently there must be a current shunting the domain capacity. If the domain drifts slower then this current decreases because the domain drift velocity and the external electron velocity are approximately equal. An equal areas rule (Fig. 4)[16] shows the relation between the highest field in the domain (E_{high}), the external low field (E_{low}) and the domain velocity. E_{high} increases as the domain charge and volts increase but the domain drift velocity decreases. Thus the current shunting the domain decreases. This effect is represented as a fixed shunting current I_D together with a voltage dependent negative resistance $-R_D$ across the domain capacity. If the domain is allowed to drift into the anode then it is forced to be discharged. This effect is represented by a discharging current generator $I_a(t)$ across the domain capacity.

A switch must short out the domain circuit when the domain is absent so that the diode then behaves with its low electric field properties: a resistance R_o shunted by a capacity C_o. The switch must open when the voltage across R_o exceeds the critical value V_c required to produce the domain. It does not close again unless the charge disappears from the domain either by the domain being discharged at the anode or by the circuit current draining the domain of charge. This is the basis of the equivalent circuit (Fig. 5). Although it has been formulated from the behaviour of a steady state dipole domain[17] it is still qualitatively valid for dynamic state and the accumulation domain. A dynamic form[18] of the equal areas rule is needed to show this.

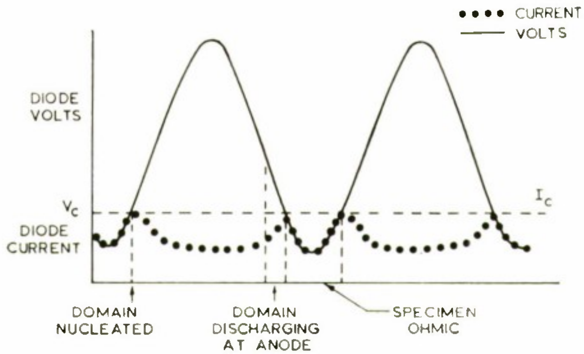
Without a computer only rough estimates can be made of the circuit parameters which depend in detail on the semiconductor properties such as length or conductivity and on operating voltage. C_D can be estimated from the average separation between the accumulation and depletion layers in

the domain. It therefore varies from the low field capacity C_o (appropriate to the initial stages of the accumulation domain) up to very many times C_o (appropriate for the small dipole domain). The dipole domain grows with increasing voltage so that C_D varies with domain volts. The domain negative resistance $-R_D$, which is a direct result of the negative resistivity of the material in the high field domain, also varies with domain voltage. Its order of magnitude is given by $-4R_o (C_o/C_D)$ at low voltages and tends to infinity at very high voltages. I_D essentially equals the critical current I_c at which domains form. However at high domain voltages one may use the approximation that R_D is infinite with I_D equal to $I_c(v_s/v_c)$, the value appropriate to the saturated domain velocity v_s.

The current generator $I_a(t)$ only operates if the domain is discharged by leaving at the anode. Its magnitude is determined by the amount of charge on the domain when it leaves. The spectrum of $I_a(t)$ depends on the domain's dimensions but in general yields a pulse of current over a time that is short compared to the transit time.



(a) Resistive transit time



(b) Resonant transit time

FIG. 6. Current generator modes.

Domain Modes of Oscillation

Using the equivalent circuit, three mechanisms of microwave generation can be more easily understood. Firstly, there is the current generator $I_a(t)$ that is only present if the domain completes a transit through the diode. This gives rise to transit time modes. Secondly there is a negative resistance associated with a domain's presence and this can lead to oscillations in which the domain does not travel across the whole diode. Thirdly one finds that the insertion and removal of the domain capacity can effectively cause parametric conversion of d.c. into r.f.[19].

Transit time modes

The overall series resistance, R_s (Fig. 5b), of the diode can be positive or negative depending on the frequency ω. When R_s is positive oscillations can be produced by the transit time current generator. There are two such modes that should be mentioned. These depend on whether the external microwave circuit is a resistive load or a resonant load.

Resistive load

When the voltage across the diode exceeds V_c a domain is formed near the cathode and travels through the specimen. As it leaves at the anode a new domain is formed in the specimen in order to absorb the voltage, in excess of V_c, across the diode. The current generator $I_a(t)$ then behaves as a pulse generator timed by the transit time of the domain through the specimen. This is the classical transit time mode discovered by Gunn and a characteristic waveform is shown in Fig. 6a. Voltage tuning is to some extent possible because the domain velocity can be altered by the applied voltage. It is not a good oscillator mode because it is rich in harmonics and not well stabilised in frequency.

Resonant load

If a parallel resonant LCR circuit is placed across the Gunn diode, it will act as a frequency filter for the transit time mode. The domain capacity will lower the effective resonant frequency of the circuit which should be selected close to the transit time frequency, or one of its harmonics. However if the circuit impedance is high enough, the r.f. voltage will be large enough, so that the total voltage across the diode falls below V_c for a time (Fig. 6b). A new domain is therefore inhibited, for this time, from forming[20]. This gives an effective circuit controlled tuning mechanism in which the transit time is only a proportion of the oscillation period. A useful tuning range of almost an octave with efficiencies around 5% are theoretically claimed for this mode[21], in fair agreement with experimental results.

Negative Resistance Modes

Self modulated modes

R_s can be negative at low frequencies, where C_D has a high impedance, yet be positive at higher frequencies where C_D has to some extent shorted out the domain resistance $-R_D$. If a suitable low frequency circuit is associated with the diode, the low frequency negative resistance can be used to modulate the Gunn diode while it simultaneously oscillates in a transit time mode at a higher frequency. This combination might also be used to make an amplifier (low frequency) combined with a local oscillator (transit time frequency) and using the inherent non-linearities for mixing. A similar scheme has previously worked[22] though using growing space charge wave negative resistance and not domain negative resistance at the lower frequency.

Quenched domain and L.S.A. modes

When the total series resistance R_s is negative at frequencies above the transit time value, oscillations can be observed at these higher frequencies[10, 23]. With a LCR resonant circuit, the r.f. voltage and current can build up so that, before the charge accumulation layer has completed a transit, the domain is discharged by the r.f. current draining charge from it. Fig. 7 shows the qualitative relation between the specimen current and voltage.

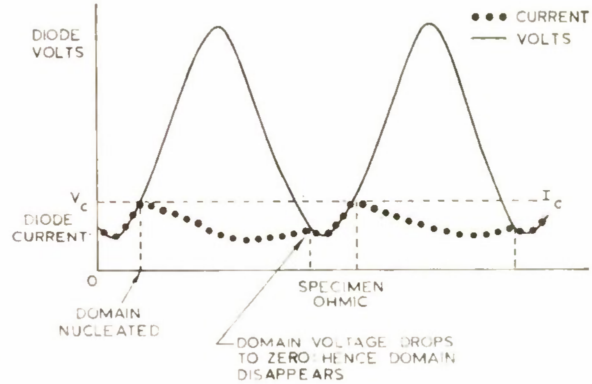


FIG. 7. Negative resistance modes (Quenched domain modes or L.S.A. modes).

The accumulation domain, with its low capacity, readily yields an overall negative resistance at high frequencies. This is the basis of the limited space charge accumulation (LSA) mode in which the whole specimen is essentially the domain. The charge accumulation is limited in value, by limiting the applied voltage, so that the high electric field falls into the region for the greatest average negative value to R_s. For a given operating frequency, the dielectric relaxation frequency has to be carefully chosen so that dipole domains do not have time to form yet the accumulation domain can be discharged in a fraction of a cycle. This leads to a condition on the ratio of conductivity to frequency of approximately $2 \times 10^{-10} \gtrsim \sigma/f \gg 1{\cdot}4 \times 10^{-12}$ mho sec. cm.$^{-1}$. A wide tuning range can be accomplished by changing the circuit. Theoretical efficiencies of the order of 10% are claimed.[21]

Parametric Energy Conversion

If a domain is present for only part of an oscillation period, the formation and removal of the domain capacity modulates the reactance of the circuit, thus enabling a negative resistance to be formed similarly to that in the well known parametric amplifier. Parametrically excited oscillations can [19, 24] be observed in a Gunn diode, at voltages above $2\,V_c$, with an inductive load across the diode. The frequency is roughly half the resonant frequency of the inductive load and domain capacity. Fig. 8 shows an idealised form for a mode in which it is only the parametric negative resistance which causes oscillation. I_D is assumed constant, with R_D infinite, and $I_a(t)$ is zero since the domain is quenched before it reaches the anode. Thus neither the domain generator nor the domain negative resistance can contribute to the power output from the device.

The source of the r.f. power can be seen most simply if a constant domain capacity is assumed. The domain charge q_D is then proportional to the domain voltage. The domain current and charge waveforms in Fig. 8 indicate that the charge is driven into the domain at a lower r.f. voltage than that at which it leaves. This is the basis of all parametric effects. In this case the power is derived from the battery. One should note that there is no charge on the domain capacity when it is introduced or leaves the circuit so that no energy is lost or gained on this account.

High circuit impedances at the harmonics of oscillation are required to prevent serious loss of power in this mode, though from experiments it appears that it is only the second harmonic impedance which is really important.

The effect, used on its own, gives over an octave of tuning and efficiencies which increase with applied voltage. The theoretical limiting efficiency depends on the peak to valley ratio, v_c/v_s, for the semiconductor material: 8% for a ratio of 1·5, 15% for a ratio of 2, or 26% for the ratio of 3 indicated by ref. 4. The effect should also be capable of enhancing the power output in the

resonant transit time mode. It is interesting to note that in a practical oscillator, where one very high efficiency (19%) has been observed[25], a high impedance at the harmonics was inserted by using an inductive load.

Conclusions

A study of the microwave mechanisms in the Gunn effect provides interesting material for speculation. A Gunn diode might be used as a parametric amplifier with built in pump, rather than as the parametric oscillator described here. The local oscillator-amplifier-mixer combination described here might be useful. The L.S.A. mode and parametric power conversion provide hopes for considerably improved efficiencies. It may be possible to combine both modes of oscillation to produce a space charge accumulation mode with the parametric negative resistance enhancing the domain negative resistance! This could be a powerful mode with efficiencies over 20%.

Unfortunately theoretical predictions are more exciting than practical reality. Pulsed efficiencies are typically less than 8% while c.w. efficiencies are usually less than 3%. Occasionally these figures are exceeded but far too often the results are poor with a tremendous variability between slices of nominally similar Ga As. Poor practical efficiencies could be accounted for by a low peak to valley ratio for the semiconductor material. Unfortunately it is not known if this ratio can be controlled or whether impurities or defects effectively lower its value. It is also found that the efficiency is sensitive to the nature of the cathode contact and how it is made. Thus, as always, technology provides the key to the future exploitation of the theory.

Output frequencies have notably been between 1 and 20 Ghz. for these oscillators, with useful powers at much higher frequencies. The difficulties of dealing with power densities around 10[7] watts/cc into the diodes has at present limited operation to around 100 mw. c.w. output or $100/f^2$ watts peak pulse (f in Ghz.). These laboratory results will probably be lower by an order of magnitude for field tests in the near future but should be increased by at least an order in the forseeable future.

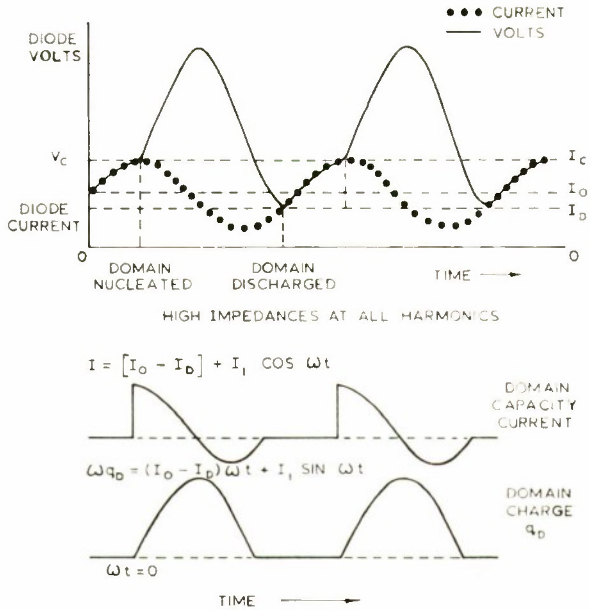


FIG. 8. Idealised parametric mode.

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SUBMARINE ESCAPE

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With the greatly increased hull and bulkhead strength of modern submarines conditions can be envisaged in which a submarine is sunk in deep water such as that over the continental shelf, all or some of the crew remaining alive. Food, water and air purification might be available for a considerable time. The Royal Naval Physiological Laboratory was therefore asked to assess the possibility of escape and to investigate the problem if such a possibility exists.

The depth of the continental shelf is taken as 600 - 700 feet of sea water and since any feasible method must involve subjecting the survivors to an equivalent pressure it will be seen that the physiological hazards involving respiration at very high pressures are present.

These are:—

(1) Oxygen poisoning
(2) Inert-gas narcosis
(3) Decompression sickness

Hazards (1) and (2) are likely to occur inside the submarine in the compression stage and must preclude an escape.

Hazard (3) is likely to appear after or during the ascent to the surface.

All these hazards are likely to be less important the briefer are the times of exposure to pressure.

The danger of oxygen poisoning could be lessened by reducing the oxygen content of the gas breathed, and that of inert gas narcosis by breathing helium instead of nitrogen. However this would complicate the procedure since special mixtures for escape purposes would have to be carried in the submarine. The hazard of decompression sickness from these great depths can only be made as low as possible by compressing the escaper very rapidly and making his total exposure to pressure as brief as possible. It was thought that if this could be done the first two hazards, oxygen poisoning and inert gas narcosis, could also be avoided since of course the body tissues can only receive gas from the blood and the latter takes a finite time to circulate (e.g. arms to tongue about 12 secs.).

In order to find out how rapidly compression had to take place goats (well tried subjects for pressure work) were used, for it was considered that the initial experiment was too hazardous to use men.

Experiments were carried out at various rates of compression and decompression involving quite a number of subjects. It is not proposed to give all the details here but the salient facts are as follows:

Depth of Sea Water (feet)	*No. of Subjects*	*Rate of Ascent*	*Compression Time (secs.)*	*No. of Bends*
600	12	5 ft./sec.	60	0
600	8	5 ft./sec.	75	1
600	8	15 ft./sec.	75	0
700	12	5 ft./sec.	60	4
700	8	15 ft./sec.	75	0

It will be seen that it is better to ascend fast, at a rate of 15 ft./sec. than at the present conventional rate of 5 ft./sec.

Considerable design work is underway to bring about an ascent rate of 15 ft./sec. and to compress in the very short times necessary. Actually it has been found possible to compress in times faster than 60 seconds (e.g. 30 seconds) which of course gives a safety bonus.

The animal experiments started at 300 feet and the depth increased in stages to 500 feet. The times of exposure to pressure varied from one to three minutes and no cases of decompression sickness were noted. It was only when depths beyond 500 feet were attempted that any cases of decompression sickness appeared.

It was then decided to subject human volunteers at depths of 300, 350 and 400 feet with a total time of exposure to pressures of one minute and these were entirely successful. Similar experiments were carried out at 450 feet with a total exposure time of 50 seconds and at 500 feet with exposure times of 40 and 50 seconds. One case of decompression sickness occurred in the 500 feet experiment. Oxygen poisoning and inert gas narcosis do not appear to pose a problem at these depths for so short an exposure time. In practice it was found that compression times considerably faster than 40 seconds were feasible and acceptable.

Uneventful experimental ascents in the sea have been made from depths down to 450 feet.

This paper was presented to the 1966 meeting of C.D.S.O., held in Canada.

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FAST-NEUTRON RADIOTHERAPY

Impressions of a Symposium held at S.E.R.L. on 30th November, 1966

Reported by J. D. L. H. Wood, B.A., R.N.S.S.

Services Electronics Research Laboratory

In recent years there has been rapidly expanding interest in the potential use of fast neutrons in radiotherapy[1-11]. The likely advantage of fast-neutron irradiation over current practice with X and gamma irradiation is its much greater effectiveness on tumour cells which have a poor oxygen supply. The symposium at S.E.R.L. was arranged as a forum for radiotherapists, for physicists concerned with the design and development of suitable neutron generators and for radiobiologists studying basic processes. Fifteen papers were presented and the neutron tube facilities at S.E.R.L. were shown to the 60 participants.

In his introduction Professor J. F. Fowler of Hammersmith Hospital took as his theme "Why Fast Neutrons?", and outlined the basic considerations involved in applying neutrons to radiotherapy. This was elaborated and developed by other speakers.

Experiments with various sources of neutrons and in a range of biological systems had shown little qualitative difference in the effects of neutron and X or gamma rays, although relative biological efficiency was found to vary from one system to another. The principal quantitative conclusion was that fast neutrons had been shown experimentally to be relatively far more effective against oxygen deficient tissue than conventional X or gamma radiation. If human tumours contain low oxygen regions, and there was much indirect evidence to suggest that this is the case, then neutrons will unquestionably be expected to improve results of treatment.

In radiotherapy the object is to destroy tumour tissue while limiting damage to surrounding healthy tissue to a tolerable level. In some animal studies with implanted tumours the relative response of tumour and normal tissue was found to be more favourable with neutrons than with X-rays and this advantage was even more favourable with fractionated treatment.

Measurements on the reaction of human skin to neutrons had established tolerance dose levels and no undesirable effects had been observed which would not equally well have been caused by an equivalent dose of X-rays. On this basis preliminary ideas on clinical trials were outlined.

With all this favourable biological evidence the emphasis was now on production of a suitable beam for clinical evaluation. It had been found possible to construct collimators for giving sufficiently well defined beams for radiotherapy and that these beams had adequate penetrating properties. There was little unwanted secondary radiation present in the beam.

The essential feature of any viable neutron radiotherapy system is the neutron generator. Sealed-off neutron tubes as developed at S.E.R.L. are of great significance compared with other neutron sources because of high output, long life and small size[11-14]. At the present stage of development the output level (10^{11} neutrons per second) is valuable for experimental purposes and a sealed tube is currently being installed at the Christie Hospital, Manchester. For the future a tenfold increase (to a level of 10^{12} neutrons per second) is essential for routine radiotherapy and development at S.E.R.L. is currently aimed at achieving a tube at this high level, specifically as a radiotherapy tool.

The consensus of opinion amongst the participants was that there was now a strong and expanding case for further work on all aspects of fast-neutron radiotherapy.

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AN ELECTRONICALLY STEERED RADAR AERIAL

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Introduction

This article describes briefly one of the electronically steered radar aerials which are being developed at present in A.S.W.E.

The main advantages of electronic steering over mechanical steering of a radar beam are the speed and flexibility in beam positioning. By making use of these advantages, usually in conjunction with computer control of the radar, the functions of steady long range surveillance and of high data-rate tracking of selected targets can be combined in one radar. The aerial described here is a compromise between flexibility and cost (which is high for a completely electronically steered beam) and is one in which the beam is electronically steered in elevation only and is scanned in azimuth by mechanically rotating the aerial. The aerial operates in C-band (a wavelength of about 5·5 cm).

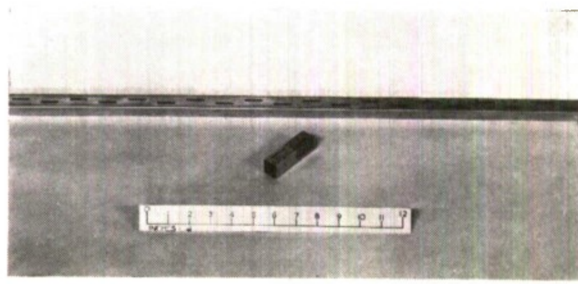

FIG. 1. A slotted ridge waveguide.

Radiating Aperture

The radiating aperture of the aerial gives a beamwidth of about 2° (at the half power points) in elevation and 1·4° in azimuth. It consists of 63 linear arrays of 62 radiators each and the radiators are spaced apart by about one half-wavelength in each direction. This close spacing is necessary to prevent the radiators acting as a diffraction grating and forming multiple beams. The linear arrays are lengths of waveguide with resonant slot radiators as shown in Fig. 1. This form of array is chosen for its lightness and simplicity. The slots are in the H plane wall of the waveguide and ridged waveguide is used in order to reduce the H plane dimension to less than a half-wavelength. The arrays are of an improved design and give radiation patterns with sidelobes lower than 30 dB below the main beam over a frequency band of 10%. A completed stack of arrays is shown in Fig. 2: the slots are covered and weatherproofed by a dielectric tape.

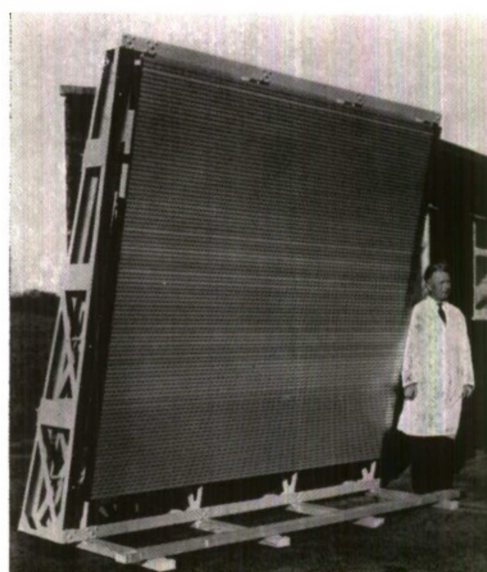

FIG. 2. A stack of slotted arrays.

Beam Steering in Elevation

The phase of each linear array relative to its neighbours is controlled by a ferrite phase shifter, one to each array, and by this means the beam is electronically steered in elevation. The manner in which the microwave power is fed to the phase shifters and hence to the linear arrays is illustrated in Fig. 3. By this arrangement the power at the input to the linear arrays is all in phase (that is the beam is unscanned in elevation) when the phase shifters are all identically set. It is in fact desirable (see paragraph 6) to have a small quadratic phase curvature introduced across the feed system and corrected by setting the phase shifters, so that the situation never exists when the phase shifters are all identically set. This small controlled phase error is introduced by dielectric inserts in the feed waveguides.

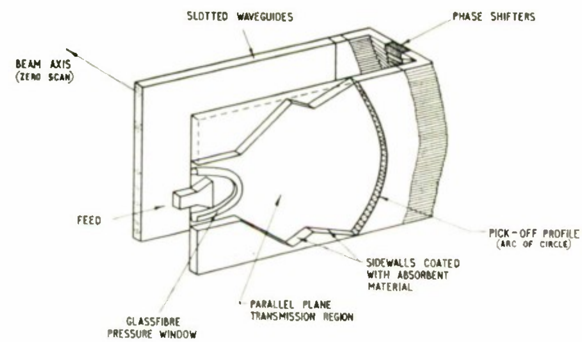

FIG. 3. Ferrite scanned stack of 63 slot arrays.

Ferrite Phase Shifters

The ferrite phase shifter is a "4-bit latching" phase shifter of a type which is being widely developed. It consists of rectangular toroids of ferrite in rectangular waveguide. The waveguide is shown in Fig. 4 with one wall removed so that the toroids can be seen spaced by white dielectric spacers and threaded by control wires with external connections. A short section of toroid to the left of the photograph shows the cross-section: the centre of the toroid is filled by a white dielectric whose dielectric constant matches that of the ferrite. The direction of remanent magnetisation of the toroid can be switched from left hand to right hand by application of a current pulse to the control wire. No d.c. current is required to hold the magnetisation since the remanent magnetisation of the ferrite used is high and there is no demagnetisation (the device "latches"). The microwave propagation constant in the waveguide is different for the two signs of magnetisation, or alternatively for the two directions of propagation

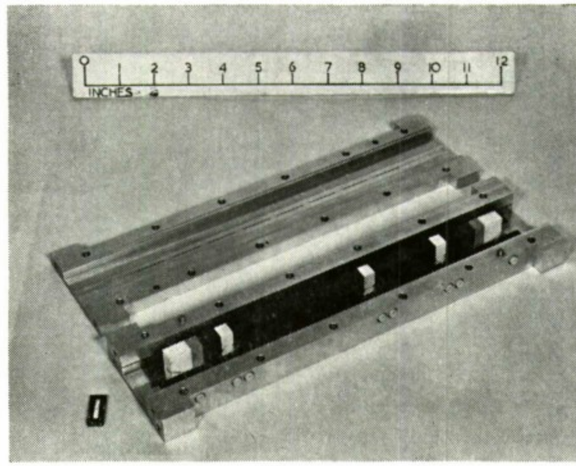

FIG. 4. Non-reciprocal digital ferrite phase shifter.

along the waveguide. The differential phase shift between the two signs of magnetisation can be made constant over a 30% band. In the phase shifter shown four toroids are used giving differential phase shifts of 180°, 90°, 45° and $22\frac{1}{2}$°, and using these "4-bits" in all possible combinations gives differential phase shift in steps of $22\frac{1}{2}$° up to 360°. The insertion loss is about 0·9 dB and the v.s.w.r. better than 0·8 over a 18% band. The peak power handling capacity is at present about 40 kW.

The manner in which the rectangular waveguide of the phase shifter makes a corner joint with the ridged waveguide of the arrays and feed is shown in Fig. 5.

Ferrite Material

The following remarks apply to materials in non-resonant ferrite devices which employ small d.c. control fields or "latch."

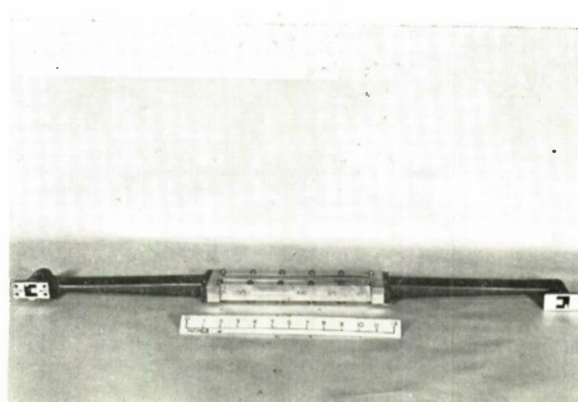

FIG. 5. Phase shifter with corner transitions to ridged waveguide.

The properties of ferrite materials in the microwave band are determined primarily by the ratio $\frac{\gamma M_s}{f}$ where M_s is the saturation magnetisation, γ is the gyromagnetic ratio usually about 2·8 Mc/s/oersted and f is the microwave frequency.

The phase shift produced by the material increases rapidly as $\frac{\gamma M_s}{f}$ is increased, but the peak power handling capacity decreases equally rapidly. A suitable compromise is usually around $\frac{\gamma M_s}{f} = 0{\cdot}5$. The peak power is limited by the critical field of the material, that is the microwave magnetic field at which spin waves are generated causing strong absorption of the microwave power. The peak power corresponding to this critical field depends of course on the cross-section area of the material and the power density within it, but it is not practicable to rely greatly on designing for low power densities in order to increase the peak power handling capacity of a device.

In the phase shifter shown the material used* is an Yttrium Iron Garnet whose M_s is reduced to about 1000 gauss by the substitution of Gadolinium and Aluminium. $\frac{\gamma M_s}{f}$ is about 0·55 and the critical field is about 13 oersted r.m.s. corresponding to a peak power handling capacity of about 40 kW. As is necessary for a "latching" device the remanent magnetisation is high (0·8 M_s) and the B.H. loop is fairly square. The Garnet materials are chosen because the temperature sensitivity of the magnetisation is low compared with other materials of acceptable microwave and B.H. properties having the desired saturation magnetisation.

The critical field is influenced by the grain size of the material when the grain size is comparable to the wavelength of the spin waves generated. In the phase shifter shown the grain size of the material is about 5 microns. A sample of the material has also been produced with a grain size

LOGIC DIAGRAM FOR CONTROL CIRCUITS.

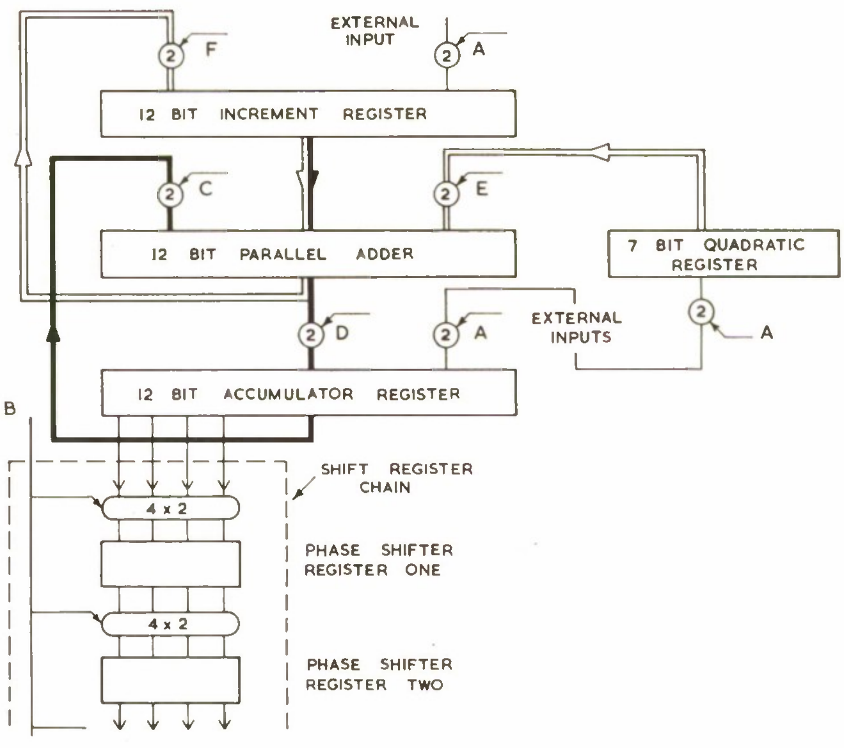

FIG. 6. Logic diagram for Control Circuits.

* Materials for these phase shifters have been developed by G.E.C. in conjunction with A.S.W.E.

of about 2 microns and its critical field was nearly doubled: a phase shifter using the small grain material should handle over 100 kW peak power.

Beam Steering Control Circuits*

This system will be slaved to a controlling computer which provides during each radar period the phase increment desired on and after the next transmission (this increment, the phase between adjacent linear arrays, completely specifies the beam's elevation angle). This information, coded in binary, is accepted into the increment register shown in Fig. 6, the most significant bit representing 180°, successive bits representing 90°, 45° *etc.*, down to about 0·1° of phase. This coding matches that of the phase shifters and also means that any overflow during computing represents 360° and can be ignored. Using the black signal paths in Fig. 6, this number can be repeatedly added into the 12-bit accumulator register, the contents of which will grow linearly during the process. After each addition the top 4-bits of this register are transferred into the first location of the shift register chain "pushing" all the existing contents down one place. This chain has 63 registers, each of these being associated with a phase shifter on the aerial. After 63 add-shift cycles the shift register chain contains a linear law along its length (more correctly, since only the top 4-bits are transferred, the contents approximate to a linear law, being at some points nearly 22½° below the progression computed in the accumulator register). This computation takes about one millisecond and is completed whilst the aerial is still receiving on the previous beam position. At a command that occurs just prior to transmission, driver circuits connected to the 4-bit registers generate current pulses that transfer the phase values in these registers into the corresponding phase shifters on the aerial. After transmission, all "bits" in all phase shifters are reversed for reception (as described previously the phase shifters are non-reciprocal, requiring a reversal of magnetisation to produce the same phase shift for waves propagating through the device in opposite directions). The time required to re-set the phase shifters is determined by the silicon controlled rectifier or power transistor used to provide the pulse and is at present 20 μsec. using an S.C.R. The inherent switching time of the ferrite is less than 1 μsec.

A closer look at the system described above reveals that the deviations caused by using 4-bit phase shifters to approximate to a linear law form a highly regular pattern across the aerial aperture. This in turn produces large sidelobes in the radiation pattern of the aerial which are undesirable. By introducing a deliberate quadratic error in the feeder network, and using the phase shifters to take this out as well as producing a linear phase shift, we can effectively "randomise" the phase error across the aperture. Although this slightly increases the r.m.s. sidelobe level it does not produce large sidelobes characteristic of the regular error. This quadratic correction is achieved by alternate use of the black and white signal paths shown in Fig. 6.

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* These control circuits have been developed by G.E.C. in conjunction with A.S.W.E.

AN ISOTROPIC DIRECTIONAL TRANSPONDER BEACON

Replying in a Direction Determined by the Incoming Signal

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SUMMARY

A three-dimensional multi-element transponder array is proposed which will give directional replies towards the sources of interrogating signals. The potentialities and limitations of the principle are briefly analysed, and a number of variants and extensions of the basic scheme are considered.

The Requirement

It is at times desirable to have a device which bounces back an amplified version of any incident electro-magnetic or acoustic signals, in the direction(s) from which these signals originated. It is normally necessary and acceptable to impose some restriction on the returned signal. This might be a restriction on the amplifier gain or a requirement that the reply signals differ in frequency from the incident wave. It is usually required to modulate the return signal to carry appropriate information back to the originator of the interrogation.

In, say, a navigational beacon system, it will be desirable that all such reply signals should appear to come from a common origin ' O '. More accurately, they will appear to come from the plane, parallel to the incident wave-front, containing point O, subject to the further delay imposed by the transducers, cables and amplifiers used in the system.

If we are indeed discussing a single system responding to all possible directions of interrogation, rather than a multiplicity of constituent directional systems, then all the receiving and transmitting transducers must be omni-directional. Clearly the required directional reply can then only be obtained from a number of such elements, suitably phased to create a phase front parallel to the incident phase front, but travelling in the opposite direction.

The Solution

This requirement can be met by any arbitrary three-dimensional array of similar transponder elements, such as those shown in Fig. 1, provided that, in each individual element, RO, the spacing of the receiving transducer R from the echo origin, O, is equal in magnitude and opposite in direction to TO, the spacing of the re-transmitting transducer from the origin.

If this spacing, in a particular element, is S and is at the angle θ to a particular incident wave front, then the receiver will be energised when the individual wave is S sin θ *in front* of O. Simultaneously (except for cable and amplifier delays) the re-transmitting transducer will then launch a suitably amplified signal S sin θ *behind* O. Hence the interrogating and reply wave fronts will pass through the origin simultaneously—except for the circuit delays which clearly must be kept equal for all the constituent transponder elements. Where the receiving transducer is behind O, for the given direction of the incident wave, the re-transmitting transducer is in front by the same amount, and the reply wave *appears* to be a reflection of the incident wave front as it passed over the origin.

Precautions Against Self-Sustained Oscillation

Difficulties would clearly arise if the amplified outputs of the (individually omni-directional) re-transmitting-transducers were themselves picked up by the receivers and, in turn, amplified and emitted. Possible means of avoiding this sort of instability include the following:

(a) Introducing a deliberate fixed delay into each receive/amplify/transmit element, ex-

ceeding the largest signal duration to be handled, and automatically blocking the repeater action of the element for a similar period following the acceptance and re-transmission of an incoming signal. This blocking pre-supposes prior recognition of the presence of a signal—a task to which this array is not very well suited. Hence blocking is probably relevant mainly when such recognition is also required for other purposes. (See also Section 7 below and the Appendix).

(b) Making the receiving *or* transmitting transducer elements partially directional, looking only outwards from O (and from other array elements). It would be preferable if both the transducers of a given element had the same limited arc of coverage. (Indeed this becomes essential if all transducers are used for both transmission and reception as discussed below). The dB gain of each amplifier must then be substantially less than the minimum overall attenuation of the aggregate (side-lobe) re-radiation signals picked up by the associated receiving transducer from the array as a whole.

(c) Changing frequency so as to transmit outside the pass-band of the receiving system. However, if this change of frequency is a significant proportion of the incident frequency, the spacing from the origin of the re-transmitting transducers must be scaled to match that of the receiving transducers, *measured in wave lengths* at the respective frequencies. Thus the phase advance of $2\pi(R_1 \sin\theta)/\lambda_1$, due to a receiving transducer ahead of one in the reference plane through the origin, is equalised by the phase lag of $2\pi(R_2 \sin\theta)/\lambda_2$, due to the re-transmitting transducer's position behind the hypothetical transducer in the reference plane, provided that $R_1/\lambda_1 = R_2/\lambda_2$ (where R_1 and R_2 are the distances of the receiving and transmitting transducers from the origin, λ_1 and λ_2 are the wave lengths of the received and re-radiated signals, and θ is the angle between the line joining these transducers and the wave front), *i.e.* the distances in wave lengths are equal. (The phase changes due to cable delays and due to the common local oscillator are of course common and so immaterial). These co-phasal contributions from different transponder elements will however no longer start arriving at the reference plane at the same *time*, so that a sharp rise (or fall) of of the incident signal will degenerate into a ramp whose duration matches the spread of

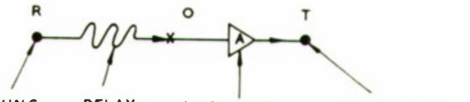

FIG. 1(a). Transponder element.
O=Geometrical midpoint between R and T i.e. RO=OT=S
The delay cable standardises the total path length R-T.

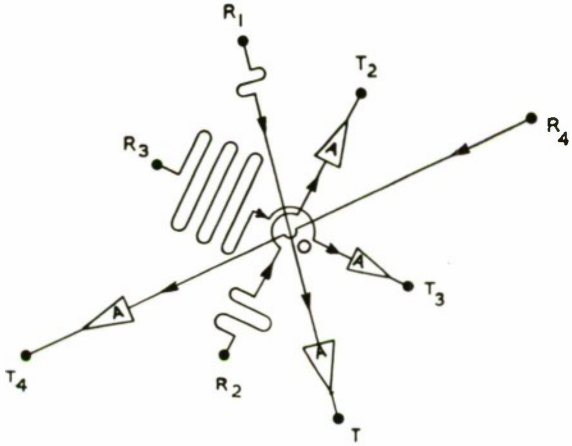

FIG. 1(b). Isotropic directional transponder. common cross over is origin O
In all four pairs, the direct-distance $R_xO=OT_x$
Including the equalising zig-zags, the total cable lengths R_xT_x are all aqual.

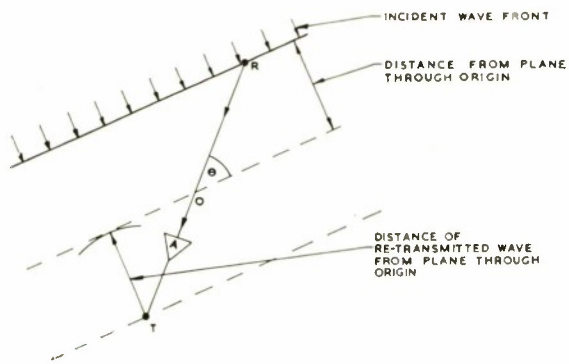

FIG. 1(c). Principle of operation.

arrival times. Hence any desired modulation of the signal must have an auto-correlation time slow compared with this time spread. (Moreover, any deliberate modulation, though applied to all the amplifiers at the same time, will be spread out according to

the time the re-transmitted wave takes to traverse all the transmitting transducers, as discussed more fully later. Even this larger time "smearing" is rarely a significant restriction on the modulation bandwidth).

For most purposes the frequency-transposition technique (solution (c)) would probably impose least restriction on the design and operation of the system.

Duplex Operation

With method (c) above, input and output signals can be distinguished in frequency, and with method (a) they are separated in time. In the absence of the scaled spacings discussed under (c), it would then be possible to use both transducers of an element both for transmission and reception, employing now two amplifiers for each of these duplex elements. The same result can also be attained with method (b), using hybrid transformers to separate the two directions of signal flow.

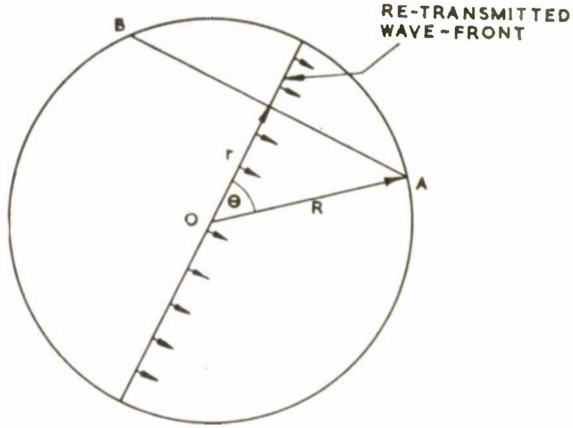

FIG. 2. First order indication of equivalent aperture distribution for uniform volume density of transducers

For uniform density of transducers within disc, number in AB $\propto$ length AB $= 2R \sin\theta$.

Directivity Patterns

Some indication of the directional gain of such a device is obtained from the consideration that the radiations from all the elements will add in phase, in the desired direction, and that they will, in general, add in more or less random phase in other directions. The beam width will of course be determined by the aperture (in wave lengths), and the beam shape by the effective aperture distribution—although a three-dimensional array like this will not give a simple co-phasal equivalent planar aperture distribution. However, if the system has any significant directional discrimination, the length of the "near field", along the direction of propagation (*i.e.* the Rayleigh distance) is large compared to the aperture—and thus compared to the "depth" of the array. Furthermore, the system is designed to produce a common plane, tangential to the co-phasal constituent circular wave fronts from the individual radiating elements. Hence some indication of the effective aperture distribution may be obtained by simply projecting the solid distribution on to a plane wave-front. (Clearly the number of transmitter elements in a "tube" parallel to the direction of propagation would normally be different for "tubes" passing through the centre of the solid array and tubes only just intersecting the circumference, tangential to the direction of propagation).

If the transducers were distributed with uniform density over a spherical volume of radius R, surrounding O, their projected density over the wave front would vary as $\sin\theta$, at radius $r=R\cos\theta$ (see Fig. 2). If they were uniformly distributed over a thin spherical shell of radius R, the projected density would vary as $\operatorname{cosec}\theta$* with the radius $r=R\cos\theta$ (see Fig. 3). Hence the density of elements may be varied as a function of their spacing from the centre of a spherically symmetrical array, and/or the amplifier gain may be made a function of this radius, and thus we can control the effective amplitude distribution over the equivalent planar array aperture, within the range of functions likely to be desired for the adjustment of the system's directivity and side-lobe patterns.

Non-Uniform Directional Characteristics

Obviously the proposed scheme can be modified as required for less than complete omni-directional coverage, or for non-conical main-beam shapes. For instance, a horizontal flat disc array would give a horizontally directioned response with vertical fan beams (see Fig 4a). There would however still be some end-fire directivity in the vertical dimension, unless the system was reduced to a broadside operating line array with restricted horizontal coverage (see Figs. 4a and b).

If the vertical distribution of possible sources of interrogation were restricted to a thin horizontal disc, the transducers could be restricted to a two-dimensional (horizontal) distribution of long vertical elements with appropriate vertical directivity patterns. If all these receiving transducers of a directional transponder were confined to a single vertical plane, the array gain would vary between the broadside and end-fire conditions. Also the system would be unable to distinguish between

* Subject to an upper limit of $\sqrt{(2R/d)}$, where d is the thickness of the shell.

angles of arrival of $+\phi$ and $-\phi$ relative to the plane of the array and would re-radiate beams at both $+\phi$ and $-\phi$ relative to the plane containing the re-radiating elements—unless the individual transducers had directional characteristics restricting their arc of coverage. Similarly, a line array would respond to signals from all directions—with a gain depending on the angle of the signal relative to the receiving line array, and would form a hollow conical re-radiated beam with the semi-vertical angle ϕ relative to the re-transmitting array (see Fig. 4b).

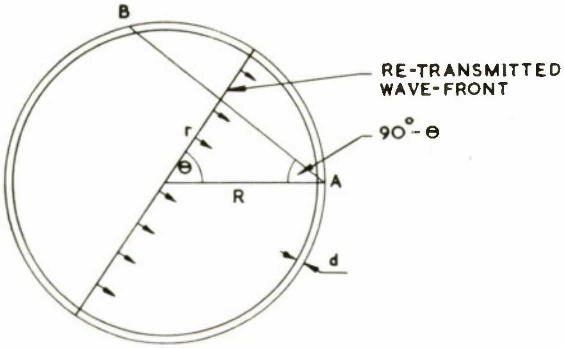

FIG. 3(a). Thin shell of transducers.

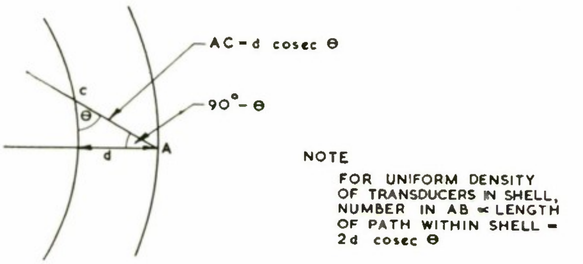

FIG. 3(b). Enlarged view of region near A.

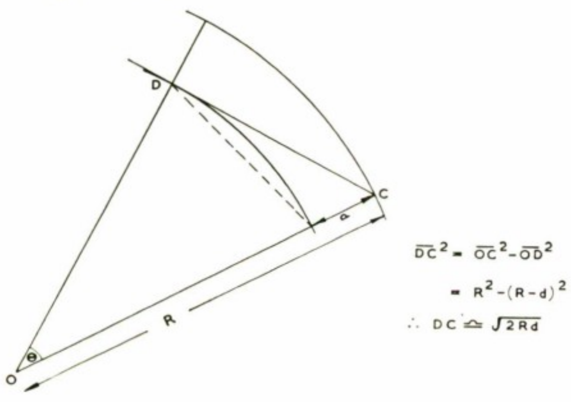

FIG. 3(c). Maximum of aperture distribution for thin shell of transducers.

Modulated Directional Replies

In general, the interrogator is likely to desire some information from the transponder other than its mere existence. Such further information can indeed be provided, if the amplifiers associated with the system are subjected to a common modulation. Such a modulation must however be restricted to an auto-correlation time not less than the transit time of a signal through the diameter of the array, so that the coherence of the modulation imposed on the re-radiated signal is maintained, irrespective of its direction (see also Precautions (c)). This should not normally prove to be an irksome restriction.

For example, an aperture of 10 wavelengths would give a beam width of approximately 0·1 radians, but the energy due to any modulation, applied synchronously to all the amplifiers, would be spread out over 10 wavelengths of the returned r.f. wave, *i.e.* 10 cycles of the carrier frequency. The energy distribution across this length is normally tapered, being maximum in the middle, where a slice parallel to the wave-front intersects the maximum proportion of the volume of the solid array. Nevertheless, the system would clearly become rapidly inefficient, if a half-cycle of the modulation frequency were less than 10 cycles of the carrier frequency, thus giving an effective bandwidth of roughly 5%, in this example.

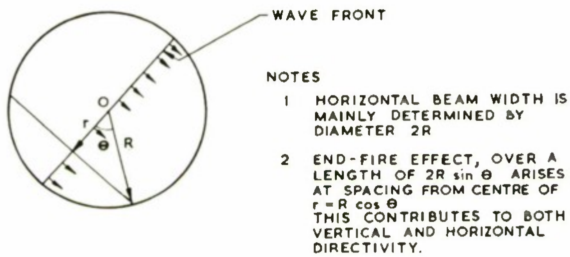

FIG. 4(a). Indication of radiation pattern from an edge-on disc array.

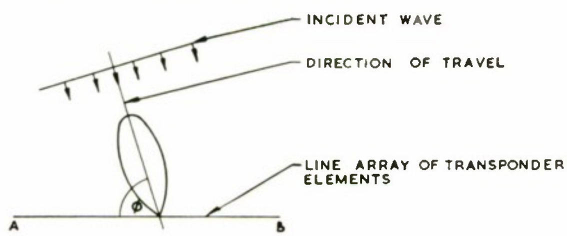

FIG. 4(b). Radiation pattern from line array. By axial symmetry, reply wave is a hollow cone, of semi angle ϕ, due to revolution of shape shown about axis AB. The beam width is determined by the projected aperture, i.e. the width of the wave front of given direction intercepted by the array.

The proposed system is best suited to a beacon or other type of *automatic* transponder or interrogation-triggered transmitter. The relative propagation delays along the *unknown* direction of re-radiation are required to bring the signals from the constituent transponder elements into phase coincidence. Hence the benefit of combined simplicity and directional gain is not available for the *recognition* of the receipt of an interrogation, prior to sending out a reply. The reply could of course be steered by the—suitably stored—signal or by further received signals. The recognition of interrogation would however have to rely on a separate, omni-directional receiving system, or else a receiving system that combines directional gain with directional search, using multiple pre-formed beams or scanning as described, for instance, in the Appendix.

Tolerances

In a directional transponder, the spacing of the two transducers of an element, with respect to the "origin", must be kept equal (and opposite) within a small fraction of the appropriate wave length, and the circuit delay must be kept constant, from one element to the next, to a small fraction of the carrier cycle time. These requirements are no more severe than those of normal transducer or aerial arrays and distributed coherent amplifier systems, and are well within the "state of the art". For instance, an equi-probable distribution of phase errors over $\pm\delta$ would produce a relative gain of $[(\sin\delta)/\delta]^2$. This is approximately 0·8 for $\delta=\pi/4$, *i.e.* for tolerances of $\pm\lambda/8$ (λ=wavelength). Indeed in many conventional array aerial designs this tolerance might not be acceptable, because the relatively small proportion of energy diverted from main lobe can have a relatively serious effect on the side-lobe pattern. However, in the isotropic transponder it would probably be impracticable to achieve a closely-defined side-lobe pattern, optimised for all possible directions of the incident wave, and hence $\pm\lambda/8$ might constitute quite a reasonable tolerance for many transponder applications.

Re-Radiation with Changed Direction

It has been shown that elements comprising transducers arranged diagonally opposite, with respect to the origin, reverse the direction of the phase front. Conversely, it is self evident that if the transmitting and receiving transducers of an element are co-located, the incident and amplified directions of propagation coincide. More generally, if the receiving and transmitting transducers of an element are equi-distant from the origin but at angles differing by θ, ϕ and ψ with respect to three orthogonal axes passing through the origin, then the re-transmitted wave front is turned through the same angles θ, ϕ and ψ relative to the incident wave front, irrespective of the direction of the incident wave. (In this general case, duplex operation of the two transducers of an element is not permissible, since $+\theta \neq -\theta$ except when $\theta = 0$ or $\theta = 180°$). This principle is most easily illustrated by considering those receiving transducers which happen to be in a particular plane, and arranging the corresponding transmitting transducers in an appropriately rotated plane (see Fig. 5).

Transformation of Mode, Medium or Frequency

The re-transmitted wave could also be an analogue of the received wave, in a different mode and/or a different medium. In that case, the spacing of the transmitting transducers would have to be scaled in proportion to the speed of the transmitted wave, assuming that the frequency is maintained: The scaled spacings ensure balance of transit *times* of the received and re-transmitted waves, in front of and behind the wave-front through the origin (see Section 2), and the common frequency ensures that these common total times also result in a common total *phase* change (expressed in wave lengths). Alternatively, or additionally, the frequency may be changed, provided the spacings are further scaled as requisite—again keeping the spacings in wave lengths constant—as already discussed under Precautions. In some applications, such scaled re-radiation might be useful for forming a scale model of a received wave, for more convenient display or analysis.

Applications

Possible applications of this scheme include:

(a) Navigational or identification beacons.
(b) Echo-enhancing or identifying transponders.
(c) "Selective broadcast" communications systems, including satellite communications.
(d) "On-demand" directional release of stored messages.
(e) Monitoring or telemetry from and/or to mobile vehicles.
(f) Signal transformation for modelling as discussed in the last Section.

In application (c) the proposed scheme would provide a transmitting or relay station which automatically restricts its radiation, in time and direction, to the requirements of the user, whilst not needing any "conscious" knowledge of these requirements. In application (d), a message previously received (or generated) at the transponder station is stored there for transmission at times and in directions controlled by the intending recipients.

This simplifies operating schedules and minimises both power dissipation and interference. Application (e) would use the same principle for, say, aircraft or satellite interrogation of oceanographic buoys or simple surface monitoring or telemetry of airborne or satellite vehicles.

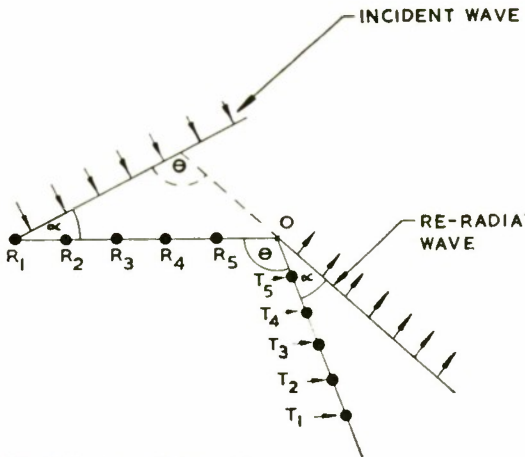

FIG. 5. Re-transmission with a fixed change of angle.

Acknowledgement

The author would like to thank Mr. P. R. Wallis for his helpful comments.

References

(1) R. Benjamin. Modulation, Resolution and Signal Processing in Radar, Sonar and Related Systems. Pergamon 1966. Sections 8 (e), (f).
(2) R. Benjamin. Patent Application No. 41612/66.

APPENDIX

Scanning Directional Reception

A transducer system may have to provide omnidirectional reception, with high array gain *and angular discrimination*. The signals from a generalised three-dimensional array of receiving transducers can of course be processed, in separate special circuits, to generate the appropriate number of pre-formed beams, for independent parallel direction-conscious reception (or transmission). However, the generation and observation of all possible receiving beams might also be time-shared, in a single channel, without loss of performance:—

In principle, any three-dimensional system of transducers can be made to search with the full coherent array gain for signals from all possible directions. For convenience this will be illustrated in terms of a flat-disc array, with all signal sources contained within its plane (suitably extended). Consider therefore a receiving transducer at distance r and angle θ, in this plane. Let this be connected to a cyclically varying delay device, delaying the signal by $[R + r \cos(\omega t - \theta)]/v$, where v is the velocity of propagation and R is greater than any r. (See Fig. 6). Thus all element signals for a source in direction ωt are delayed by the time it would otherwise take them to reach a common wave front at distance R beyond the origin, and so can be added coherently in a common output circuit. Hence the system scans in angle at the rate ω.

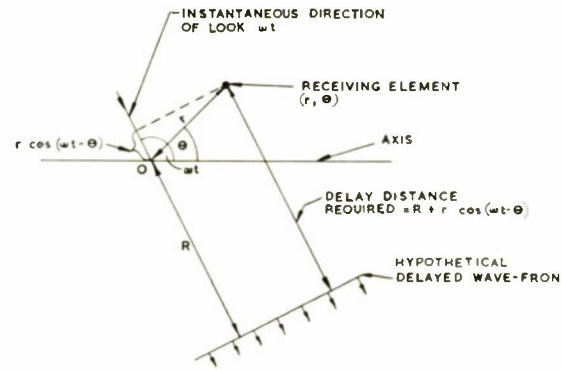

FIG. 6. Variable delay requirement for a scanning receiving array.

The bandwidth of the output circuits must then clearly be at least $n\omega/2\pi$, if n resolvable directions of arrival are to be covered. Conversely, the half-cycle time of the received signals must not be less than the transit time of its wave front over the array, if all the element signals are to be capable of coherent addition. Finally, at least one complete angular scan must take place during each half cycle of the signal bandwidth, if no potential signal information—or signal-to-noise ratio—is to be lost.

These requirements may be re-stated as follows:

(output circuit response time) < (scan cycle time)/n;

(scan cycle time) < (signal auto-correlation time);

(signal auto-correlation time) > (propagation time over the array).

Thus the cyclic delays, applied for angular scanning, must be less than the signal auto-correlation time, *i.e.* the half-cycle time at the signal bandwidth. Hence it is permissible to represent the cyclic delay variation by a cyclic phase change; if desired, this can alternatively be represented by the appropriate cyclic frequency change. This subject is treated more fully in Reference 1, with regard to linear and circular arrays. It must be re-emphasised that these elaborations for spatially coherent directional *reception* are not required for (or indeed relevant to) *automatic* directional re-transmission.

A LAPSE OF TIME
New Light on the Lorentz Transformation

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SUMMARY

A graphical model of the restricted Lorentz Transformation is constructed, in which time and distance are represented by real lengths. Consideration of the symmetry of measurements made by two observers in uniform relative motion of events occurring at their centre of mean position shows that two clocks which are synchronized when the observers are together must remain synchronized when they move apart with the observers. Disagreement between the measured times of other events is caused solely by the rules of measurement and invariance of the speed of light.

Plans for a voyage to the stars outlined earlier[1] in this Journal are based on the widely held belief that, by the Lorentz transformation of Special Relativity, the time which elapses on board a space-ship is less than the corresponding time on Earth. This is coupled with a belief that it is permissible to divide the distance of the ship as measured from Earth by the time which has elapsed on the space-ship clock, to obtain a proper speed which always exceeds the measured speed and can theoretically exceed the speed of light.

Time, it is implied, would pass more slowly for a man in the space-ship than for those whom he leaves behind on Earth: after a long flight to a distant star, the space traveller might expect to return to an Earth which had aged by centuries during his normal span of life.

A similar view is expressed by almost every writer on the Theory of Relativity[2, 3, 4] but many ordinary scientists are worried by this unsymmetrical interpretation of the Lorentz transformation, which appears to them to be contrary to the spirit of Special Relativity. The transformation may be inverted to exchange the rôles of two observers in uniform relative motion and it may be argued that the elapsed time of each is less than that of the other. No resolution of this paradox is possible unless the two observers can meet again to compare clocks, but this would involve relative acceleration between them, which is not covered by the Lorentz transformation.

Our purpose is to suggest that no paradox exists and that disagreement of measured times of the same event is caused solely by the rules of measurement together with the invariant speed of light. Publication of these ideas has been encouraged by a recent anthology[5] containing a speculation on the Observation of Line Events in Special Relativity by Professor Dingle, who has always courageously insisted on the symmetry between observers in relative uniform motion.

Rules of Measuring Time and Distance of an Event

Considering only one dimension of space, let P be a particle, and at time t let x be the distance of a second particle P′. The method of measuring t and x is such that if a light signal is emitted from P at time t_1 as recorded by a clock at P and its reflection from P′ is received at t_2 according to the same clock then

$$t=(t_2+t_1)/2 \qquad (1)$$

$$x=(t_2-t_1)/2 \qquad (2)$$

in which the velocity of light is taken to be unity. These rules for defining the time and distance of an event by observations made at P are simple,

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Professor Dingle has told the Author that he no longer believes in the validity of the Lorentz Transformation.

reasonable and in agreement with the way in which radar measurements are made.

If a later measurement reveals that at time $t+\delta t$ the distance of P′ was $x+\delta x$, then the velocity of P′ relative to P at time t is

$$\frac{dx}{dt} = \lim_{\delta t \to o} \frac{\delta x}{\delta t} = v, \text{ say.}$$

When v is constant similar measurements of the distance x' of P from P′ as a function of time t' by a clock at P′ will reveal that the velocity of P is $-v$, the velocity of light again being taken as unity by an observer at P′.

Set both clocks to zero when $x=x'=0$ and let (T, X) and (T', X') be the times and distances of any event E observed from P and P′ respectively. Then it has been shown[2] that the rules of measurement (1), (2) lead to the restricted Lorentz transformation relating the two pairs of measurements:

$$T'=(T-vX)/\sqrt{1-v^2}, \quad (3)$$

$$X'=(X-vT)/\sqrt{1-v^2}. \quad (4)$$

This transformation is restricted because, it is sometimes said, the relative motion of the two particles lies in the common direction of the axes of X and X'. If an event E does not lie on the x-axis but has co-ordinates (T, X, Y, Z), (T', X', Y', Z'), then (3) and (4) are unchanged, but additionally, $Y'=Y$, $Z'=Z$.

Geometrical Representation

If time and distance are regarded as two co-ordinates of an event, a well-known geometrical representation of the Lorentz transformation is obtained by putting

$$T = x_1, \ iX=x_2 \ ;$$

$$T'=x'_1, \ iX'=x'_2;$$

and $iv=\tan\theta$;

so that (3) and (4) may be written

$$x'_1=x_1 \cos\theta + x_2 \cos\theta, \quad (5)$$

$$x'_2=-x_1 \sin\theta + x_2 \cos\theta. \quad (6)$$

Hence if the axes of (x_1, x_2) are orthogonal, the transformation is equivalent to a rotation of the axes through an angle θ, equal to arctan (iv). What then is meant by the common direction of the axes of X and X' ? One answer is that it is the line joining P and P′ in three-dimensional space.

The origin of time and space is at the point where the relatively moving particles coincide and their clocks each read zero. If the event is at P then $x_2=0$, so that $x'_1=x_1 \cos\theta$, where $\cos\theta$ is greater than unity because θ is imaginary. This leads people to say that the elapsed time at P′ is greater than at P; but our contention is that only the measured time of the event is different at the two points.

To support this view we seek a geometrical construction for the Lorentz transformation in which time and distance are represented by real lengths. This may be done by putting $v=\sin\phi$ in (3) and (4) to give

$$T'=(T-X\sin\phi)\sec\phi, \quad (7)$$

$$X'=(X-T\sin\phi)\sec\phi, \quad (8)$$

which is a transformation from one pair of oblique axes O (t, x) inclined at an angle $(\pi/2+\phi)$, to a pair O(t', x') which makes angles respectively of ϕ and $\pi/2$ with Ot (Fig. 1).

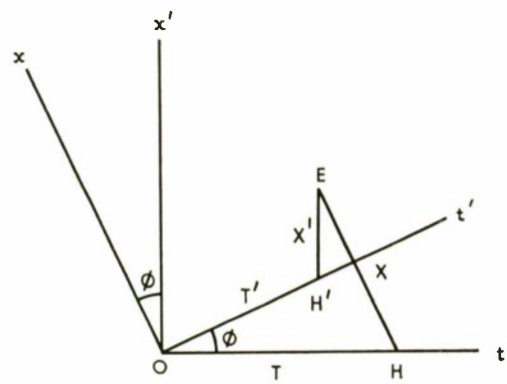

FIG. 1.

If H and H′ are the oblique projections of that point which represents the event E on the axes of t and t', then

$$OH = T, \quad HE = X;$$

$$OH'=T', \quad H'E=X'.$$

It will be noted that HE is perpendicular to Ot' and H′E is perpendicular to Ot.

This diagram is a very convenient way of visualising the co-ordinates of any event measured from

two points P,P′ which have a relative speed $v=\sin\theta$ (the speed of light being unity, always). An event occurring at P at clock-time T_1 is represented by a point on the axis Ot at distance T_1 from O, and a later event at time T_2 would be represented by a point at distance T_2 The sequence of all such points represents the passage of P through time as measured on a clock at P. This is the axis Ot, which we shall call the track of P in the space-time diagram. Similarly the track of P′ is the axis Ot'.

The kinematics and dynamics of particles other than P′ which also move relatively to P have been well studied in Special Relativity, and we now ask, what is the track in our diagram of any uniformly moving particle Q?

Track of a Moving Particle

If measured on a clock at P a particle Q has a distance X_1 at time T_1 and distance X_2 at time T_2 (Fig. 2), its velocity relative to P will be said to be

$$u=\frac{X_2-X_1}{T_2-T_1}.$$

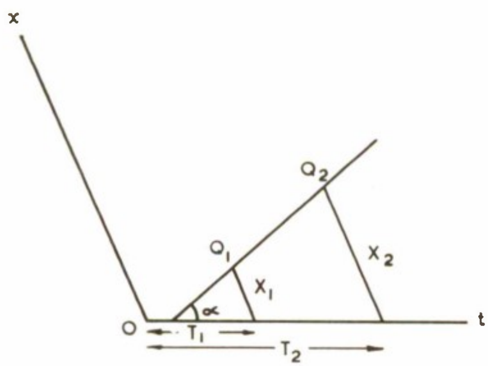

FIG. 2.

If the track Q_1Q_2 of Q makes an angle α with Ot, then

$$u=\frac{X_2-X_1}{T_2-T_1}=\frac{\sin\alpha}{\sin(\pi/2+\phi-\alpha)}$$

$$=\frac{\tan\alpha}{\cos\phi+\tan\alpha\sin\phi}; \quad (9)$$

$$\text{so } \tan\alpha=\frac{u\cos\phi}{1-u\sin\phi}=\frac{u\sin(\pi/2+\phi)}{1+u\cos(\pi/2+\phi)}. \quad (10)$$

We also find by a similar construction that the velocity of Q relative to P′ is given by

$$u'=\tan\alpha\cos\phi-\sin\phi. \quad (11)$$

Adding the velocity of Q relative to P′ to the velocity of P′ relative to P by the relativistic law for addition of velocities, gives, for the velocity of Q relative to P:

$$\frac{v+u'}{1+vu'}=\frac{\sin\phi+\tan\alpha\cos\phi-\sin\phi}{1+\tan\alpha\cos\phi\sin\phi-\sin^2\phi}$$

$$=\frac{\tan\alpha}{\cos\phi+\tan\alpha\sin\phi}=u, \text{ as required.}$$

This is a check.

If Q is a light signal then $u=u'=1$ and then by (10) or (11)

$$\tan\alpha=\frac{\sin(\pi/2+\phi)}{1+\cos(\pi/2+\phi)}=\frac{1-\cos(\pi/2+\phi)}{\sin(\pi/2+\phi)}$$

$$=\tan(\pi/4+\phi/2), \quad (12)$$

$$\text{so} \quad \alpha=\pi/4+\phi/2. \quad (13)$$

A light-path is thus inclined at an angle $\pi/4$ to the track of a particle M which makes an angle $\phi/2$ with Ot.

The velocity w of M relative to P is obtained by putting $\alpha=\phi/2$ in (9):

$$w=\tan(\phi/2), \quad (14)$$

and similarly, relative to P′, by (11),

$$w'=\tan(\phi/2)\cos\phi-\sin\phi$$

$$=-\tan(\phi/2). \quad (15)$$

Once again, as a check, the velocity of P′ relative to M added to the velocity of M relative to P by the relativistic law gives, for the velocity of P′ relative to P:—

$$\frac{w-w'}{1-ww'}=\frac{2\tan(\phi/2)}{1+\tan^2(\phi/2)}=\sin\phi=v.$$

Because $\tan(\phi/2)=\dfrac{\sin\phi}{1+\cos\phi}$,

therefore

$$w=\frac{v}{1+\sqrt{1-v^2}}, \quad (16)$$

and we see that the relative velocity of M in the P-system is approximately $v/2$ when v is small and 1 when $v=1$.

Let α be the track angle of any particle Q which has a velocity u relative to P. Then the velocity of

Q relative to M given by the relativistic law of addition is

$$q=\frac{u-w}{1-uw}=\frac{\tan\alpha-\tan(\phi/2)(\cos\phi+\tan\alpha\sin\phi)}{\cos\phi+\tan\alpha\sin\phi-\tan(\phi/2)\tan\alpha}$$

by (9) and (14)

$$=\frac{\tan\alpha(1-\sin\phi\tan(\phi/2))-\cos\phi\tan(\phi/2)}{\cos\phi+\tan\alpha(\sin\phi-\tan(\phi/2))}$$

$$=\frac{\tan\alpha-\tan(\phi/2)}{1+\tan\alpha\tan(\phi/2)}$$

$$=\tan(\alpha-\phi/2)\ ; \tag{17}$$

that is, the velocity of Q relative to M is the tangent of the angle between its track and the track of M.

Events at the Centre of Mean Position

A particle M whose track angle is $\phi/2$ is the one point relative to P and P′ at which events will appear to have the same times (and equal but opposite distances) in the two systems. We shall interpret M to be the centre of mean position of P and P′.

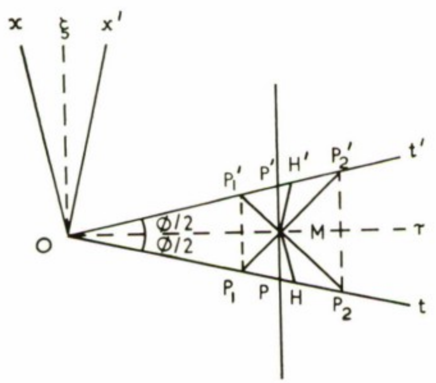

FIG. 3.

Let $O\tau$ be the track of M (Fig. 3). Let an event at M be illuminated by a light signal emitted from P at time t_1 and by a signal emitted from P′ at time t'_1, and let the measured co-ordinates of the event be (T,X) and (T',X') in the two systems where $T=T'$ and $|X|=|X'|$.

Let the times of receipt of the reflected signals be t_2 and t'_2 respectively. Then by the rules of measurement

$$(t_2+t_1)/2=(t'_2+t'_1)/2=T\ , \tag{18}$$

$$(t_2-t_1)/2=(t'_2-t'_1)/2=|X|\ ; \tag{19}$$

and therefore

$$t_1=t'_1\ ,$$

$$t_2=t'_2\ .$$

If P_1,P'_1 and P_2,P'_2 are the positions of P and P′ on their respective time axes at the times of emission and receipt of the signals, then the lines $P_1P'_1$, $P_2P'_2$ are each perpendicular to $O\tau$. We assert that these lines establish a one-to-one correspondence between events at P and P′ when their clocks record equal times. As P moves in time from P_1 to P_2 so P′ moves from P'_1 to P'_2 and their respective clocks advance through the equal intervals (t_2-t_1) and $(t'_2-t'_1)$. The elapsed time is therefore the same for each.

An event at P_1 and an event at P'_1 are *simultaneous* in the sense that the local clock times of the events are equal. This can be used as a definition of simultaneity. Reciprocal measurements of these events, that is, of P'_1 by P and of P_1 by P′ will also be equal.

The distance apart of the particles in the space-time diagram is along PP′, the line joining them, which intersects $O\tau$ at M, for surely two points and their centre of mean position are collinear in any rectilinear system of axes. The axis $O\tau$ is, in some way, the 'common' time axis and $O\xi$ drawn perpendicular to it is the 'common' space axis. The straight line PMP′ moves parallel to $O\xi$ to mark the passage of time and the tracks of all particles including light signals are generated by this line sweeping across the diagram. Events on $O\xi$ are measured to be at equal distances from P and P′ and to occur at equal but opposite times (later and earlier than zero).

We learn that the positions P and P′ corresponding to M, the event illuminated by the light signals, are not the same as H, H′ which mark the measured times of the event. When the event occurs at M the clock at P has not yet reached the time $T=(t_2+t_1)/2$ which is *afterwards* deduced to have been the time of the event upon receipt of the reflected signal at time t_2. Similarly the clock at P′ does not reach either T' or t'_2 until after the event has occurred.

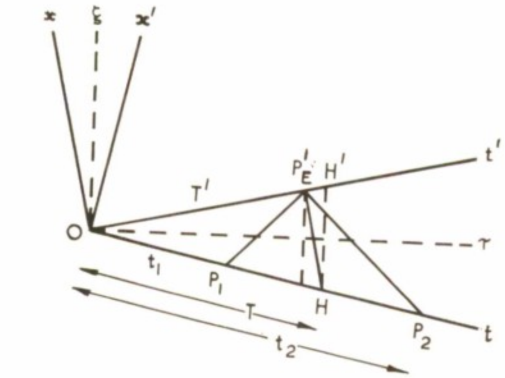

FIG. 4.

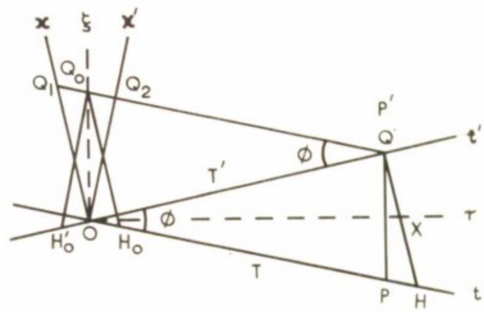

FIG. 5.

Tracking a Space Ship

Now consider the consequences of the foregoing assertions in the situation where an observer at P is continuously tracking P′ by radar.

Fig. 4 shows the light-path of a radar signal which is emitted from P_1 at time t_1 and is reflected from P'_E at time T' to arrive at P_2 at time t_2. The point H is at the measured time of the event, $T=(t_2+t_1)/2$.

In course of time the particle P will pass through H on its way from P_1 to P_2 and P's clock will record the time T, but by this time the particle P′ will have moved on from the event P'_E to reach a time $t'=T$ at H′.

Even if P′ becomes extinct immediately after time T' it will still appear to an observer at P to be in existence at time t_2, and the event P'_E will appear to have occurred at time T, which is greater than T'. So the moving particle will appear to have lived longer (in P's time) than its life on a clock at P′.

A time will come in the life of P′ when it will reach a distance object Q (such as a star) which is at a constant distance from P, and when radar echoes will be received simultaneously from Q and P′, their common distance being measured as, say, X at time T. As the clock at P′ will record a time $T'=T\cos\phi$ and as Q is not moving relatively to P it must seem that P′ has indeed travelled a distance X at proper speed X/T', which is greater than its measured speed $v=X/T$.

Let us however plot the track of Q in the oblique space-time diagram (Fig. 5). It is parallel to Ot because its track angle is given by $\tan\alpha=0$. While P and P′ each move through a time T′ (as measured by their respective clocks) Q must move along a track equal in length to OP. Its starting point Q_o is on the axis Oξ, perpendicular to Oτ.

An event at Q_o has co-ordinates (OH_o, H_oQ_o) *i.e.* $(X\tan(\phi/2), X)$ in the P-system and (OH'_o, H'_oQ_o) *i.e.* $(-X\tan(\phi/2), X)$ in the P′-system. This is the event in the distant star which *corresponds* to the departure of P and P′ from one another. It is at a measured distance X from each of them but its measured time is later and earlier than zero in the two cases.

If a clock on the star is set to zero at a time on the star which is measured to be zero by P it will then be at Q_1, on the x-axis. It will advance through time to Q and will then register T compared with the space ship time of $T'=T\cos\phi$.

Similarly if the star-clock is set to zero at a time on the star which is measured to be zero by P′, this event will occur at Q_2, on the x'-axis. The clock will then advance through time to Q, as before, but it will now register $T''=T'\cos\phi$.

Thus, on arrival of P′ at Q, the star-clock will register a time later or earlier than the P′-clock, depending on which observer sets it to zero. They cannot both be correct and it is our belief that neither is correct. The correct time at which to set the distant clock to zero is when it is on the ξ-axis, and the only observer qualified to set the star-clock is P′, *on arrival*, who will set it to T'.

A man on the star lives through a time T′ while a man on Earth lives through an equal time T', and while, we assert, a man in the space-ship also lives through an equal time T'.

The conventional view is that the space traveller can make his travel time T' as small as he likes by increasing v $(=\sin\phi)$. Our view is that even when the velocity of separation $\sin\phi$ reaches the limit of unity, the elapsed time T' does not shrink to zero, but instead the measurements T and X both tend to infinity in the ratio $X/T=\sin\phi$.

The distance OQ on the ξ-axis may perhaps be termed the 'absolute distance' of the star, and it is conjectured that this is either $2T'\sin(\phi/2)$ or $2T'\tan(\phi/2)$.

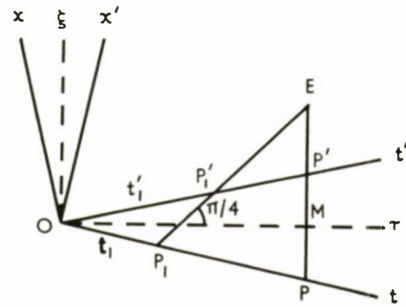

FIG. 6.

Collinearity

It may be wondered why correct synchronization of clocks between P and Q which are relatively at rest should depend on the motion of P′. The reason may be sought in the initial postulate that P and P′ are in relative motion, which defines a direction in space-time: the line joining them, at any instant on either clock. Events covered by the restricted Lorentz transformation occur on this line.

Any event such as E in Fig. 6 is collinear with P and P′ in more than one sense. It lies on the track of a light signal which leaves P_1 at time t_1, passes through P'_1 at time t'_1 and arrives at E by the time P and P′ have arrived at their final positions shown. Notice that the light signal is always on the moving line joining P and P′ and that the event E cannot occur before it arrives.

Any straight line through E intersects the axes Ot and Ot' at the points occupied by P and P′ at times (on their clocks) when they are met by a third particle which travels from P to P′ and thence to E at a speed relative to P of u, given by Equation 9. When the track angle α exceeds $\phi/2+\pi/4$ the third particle would require to travel at a speed greater than unity (the speed of light).

The fact that P and P′ cannot be connected instantaneously by a light-signal does not make two events at P and P′ any the less real. We can say that any event E on the line joining P and P′ is simultaneous with them and a clock at E would be correct, in our system, only if it registered the same time as the clocks at P and P′.

To restore ordinary English usage to the language of Relativity we can say that the event E *happens when* the clocks at P and P′ are showing their respective equal times (although it will happen unbeknown to either of the observers). Should this be thought to reinstate the concept of absolute time in Physics, then we must allow the possibility. Relativity of measurement will remain unchallenged.

Interval

The interval S, in relativity theory, between an event at P′ (*e.g.* arrival at Q in Fig. 5) and the event of departure from O is given by

$$S^2=T^2-X^2 =T'^2(\sec^2\phi-\tan^2\phi) =T'^2. \tag{20}$$

Thus while P′ is on its journey the lapse of time for all three observers P, P′, Q is equal to the interval S.

Referring again to the rules of measurement (1) and (2):—

$$T=(t_2+t_1)/2, \tag{1a}$$

$$X=(t_2-t_1)/2, \tag{2a}$$

we find that

$$S^2=T^2-X^2=t_1t_2. \tag{21}$$

This suggests a revised rule for the measurement by P of the time of an event at P′, namely

$$T'=\sqrt{(t_1t_2)}, \tag{22}$$

i.e. the geometric mean of the times of emission from P of a light signal and the receipt of its echo from the event, rather than the arithmetic mean

(1a). It also suggests a way of synchronising clocks at a distance, because a further signal from P could carry the information that at the instant of arrival of the previous signal the clock at P′ should have been set at the value given by (22).

It is sometimes said that the interval between two points on a light ray is always zero. Our diagram shows that it is not. When P′ is travelling at the speed of light relative to P, the angle between Ot and Ot' is $\phi=\pi/2$ and then, because

$$T=T'\sec\phi, \qquad (23)$$

$$X=T'\tan\phi, \qquad (24)$$

both measured co-ordinates of the event are infinite. The square of their difference, however, is still T'^2.

We interpret this to mean that although a light signal can leave O to travel in company with P′ any return signal leaving P′ will never reach P, which is receding from P′ at the speed of light. An event at P′ can be reached only by a light signal which leaves P at time $t_1=0$, but the time t_2 of arrival of a return signal at P is infinite. Their product t_1t_2 is finite and equal to T'^2.

Returning to the situation in which the speed of P′ relative to P is not necessarily unity but is $\sin\phi$, it is of interest to study the interval between an event at the origin and an event at a particle Q which travels from the origin at speed u relative to P.

In Fig. 7 let τ be the distance OM. Then for any event (T,X) at Q trigonometry shows that

$$\tau=T\cos(\phi/2)-X\sin(\phi/2)$$

$$=T(\cos(\phi/2)-u\sin(\phi/2)); \qquad (25)$$

$$\therefore S^2=T^2-X^2$$

$$=\frac{\tau^2(1-u^2)}{(\cos(\phi/2)-u\sin(\phi/2))^2}, \qquad (26)$$

If OP=OP′=D

then $$\tau=D\cos(\phi/2) \qquad (27)$$

so $$S^2=\frac{D^2(1-u^2)}{(1-u\tan(\phi/2))^2}$$

$$=\frac{D^2(1-u^2)}{(1-uw)^2}, \qquad (28)$$

where w is the speed of M relative to P.

Let q be the speed of Q relative to M, so that

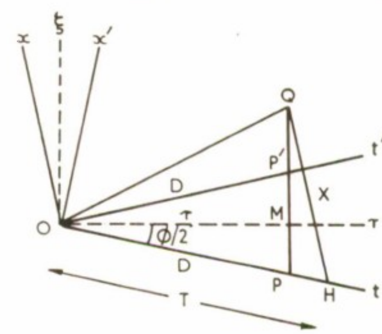

FIG. 7.

$$u=\frac{w+q}{1+wq}. \qquad (29)$$

Substitution of (29) in (28) yields

$$S=D\sqrt{\frac{1-q^2}{1-w^2}} \qquad (30)$$

which states the interval in terms of the time which has elapsed on the clock of either P or P′ at the instant when the event occurs at Q.

When $q=w$, Q is coincident with P′ and then $S=D$, as was previously stated.

When $w=1$ and $q\neq 1$, that is when P and P′ are separating at the speed of light and Q is moving relative to their centre of mean position at a speed less than that of light, the interval S between the origin and an event at Q is infinite.

When $w\neq 1$ and $q=1$, that is if P and P′ are separating at a speed less than that of light and Q is a light signal, the interval between the origin and Q is truly zero.

Experimental Evidence

We have already seen from Fig. 4 that each relatively moving observer P and P′ appears to the other to live longer than his actual life. This is not inconsistent with the experimental result sometimes quoted that the life of a high energy meson is apparently extended by its high velocity relative to the Earth. Without undertaking an analysis of exactly what has been measured in these experiments it is not possible to say whether or not they refute the assertion that two uniformly relatively moving clocks remain synchronised at

a distance, but it is instructive to consider briefly the picture in which the two observers P and P′ are approaching one another.

In Fig. 8, P and P′ are advancing along their respective time axes towards the origin O and each has an equal time $-T'$ to go. A light signal which has left P at P_1 at time t_1 (<0) will have arrived at P′ and will be reflected back to reach P_2 at time t_2 ($t_1 < t_2 < 0$). When P reaches P_2 to receive the signal, the time of reflection will be calculated as

$$T=(t_2+t_1)/2$$

and the distance of P′ at this time to have been

$$X=-(t_2-t_1)/2.$$

The time T is automatically negative but X is negative only if account is taken of the fact that to reach P′ the light signal must be emitted in the negative direction of the x-axis.

On arrival of both observers at the origin, P′ will appear to P to have travelled a distance $0-X$ in time $0-T$ at velocity $(-X)/(-T)=\sin\phi$ whereas the time which has elapsed for P′ is only $0-T'=-T\cos\phi$, the same as that which has elapsed for P.

Note that when $\cos\phi=0$, T is infinite unless $T'=0$. This is interpreted to mean that except at the origin, no communication is possible between observers who are approaching one another at the speed of light.

Conclusion

This paper has presented a view of Special Relativity which may be summarised in the following way.

Time and distance measurements of physical events made by two observers in uniform relative motion are related by the Lorentz transformation. Except for events occurring at the position of an observer these times and distances are calculated from the times of transmission and reception of light signals, each observer taking the speed of light to be unity. For distant events there is no reason to identify the calculated time with the time on each observer's clock when the event occurs and thereby to deduce that the two clock rates differ. On the contrary, in order that calculated times and distances should be related by the

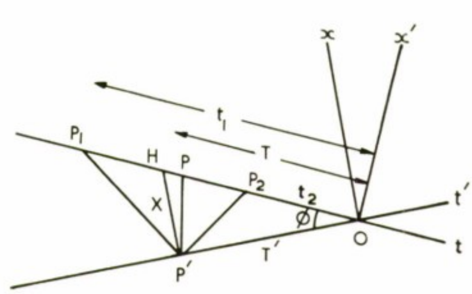

FIG. 8.

Lorentz transformation it is *necessary* that the two clocks should run at the same rate, so that the times of emission and receipt of light signals may be correctly recorded. Complete symmetry exists between measurements made by each observer of time and distance at the other. Clocks moving with them always keep in step. Time dilation is an effect of measurement and not a real difference between the times on two clocks, either when they are apart or when they return to each other.

The opposite point of view, the truth of which we deny, appears to be that the calculated time of a distant event is the same as that shown by the observer's clock when the event takes place. The elapsed time for each observer is therefore generally different and their clocks do not agree. In particular, an event which occurs at the position of one observer occurs at a later time for the other, whose clock must therefore be running faster. As this is equally true for an event at either observer we are led to a paradox. Attempts to explain this have involved an imaginary experiment in which one observer alone is decelerated (relative to what?) and returns to the other to find out who is the older. The Lorentz transformation no longer relates their measurements and we must not be surprised if their clocks differ. But the suggestion that they might differ came only from a misinterpretation of the Lorentz transformation. We are thus introducing a lack of symmetry to explain an imaginary effect which does not occur when symmetry is present.

The Lorentz transformation of Special Relativity is primarily a kinematic relationship. It does not introduce the relative masses of the two unaccelerated particles from which the observations are made. Because of the apparent importance of the centre of mean position, whose track in

space-time is an axis of symmetry, it may be that the centre of mass is really the datum to which measurements must be referred, just as in cosmology[6] the centre of mass of all matter in the universe has been identified with the physical origin. The Lorentz transformation may not be valid for two particles which are unequal in mass. When only two equal particles are involved any force between them acts equally on each. The track of each may be curved by acceleration but they will lie symmetrically about the track of the centre of mass. On meeting again the two clocks will agree. This is generally recognised by writers on relativity, but what does not seem to be admitted is the basic symmetry of the Lorentz transformation and the idea that two unaccelerated clocks would also agree if they could be interrogated by light signals sent from the centre of mean position.

We do not pretend to say what happens when a small clock is accelerated relative to the massive Earth and later decelerated to return to Earth, but maintain that there is no need to invoke such a situation in order to resolve a paradox which does not exist.

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LAUNCH OF H.M.S. *RENOWN*

H.M.S. *Renown*, the Royal Navy's second ballistic missile submarine, was launched from the Birkenhead yard of Messrs. Cammell Laird & Co. (Shipbuilders and Engineers) Ltd. on Saturday, 25th February, 1967. The naming ceremony was performed by Mrs. Healey, wife of the Right Honourable Denis W. Healey, M.P., Secretary of State for Defence, and the religious service was conducted by the Right Reverend the Lord Bishop of Chester.

The *Renown*, which is of all British construction, has a length of 425 ft. and a beam of 33 ft. Her main machinery consists of a pressurised water reactor driving a single shaft through steam turbines and she will be fitted with the latest developments in underwater detection and navigation. She will carry 16 Polaris A3 missiles with a range of 2,500 miles and capable of being delivered with extreme accuracy. In addition she has six 21 in. torpedo tubes.

The submarine, fitted with the latest air conditioning and purification equipment, will be able to undertake patrols of long endurance at high underwater speeds. The nuclear plant is being furnished by Messrs. Rolls Royce and Associates Ltd., and the steam propulsion machinery by Messrs. Vickers Ltd., of Barrow.

To ensure that this submarine spends the maximum time at sea she will, like others of her class, have two complete crews. Each crew will comprise some 13 officers and 128 ratings, a large proportion of whom will be from highly skilled categories. The two crews will be known as Port and Starboard and they will take turn and turn about on the schedule of patrols.

Accommodation for her crew will be of the highest standards and, in view of her rôle, particular attention has been paid to habitability; this includes water distilling plant to provide unlimited fresh water for shower baths and for the fully equipped laundry. Meals will be served on a cafeteria system from a large modern galley with separate messes for senior and junior ratings on either side.

Special attention has been given to the decoration and furnishing of the living quarters and recreational facilities which will include cinema equipment, a comprehensive library and tape recordings.

Both captains of the *Renown* are aged 38 and served together for a short time during 1956-1957 at the submarine base, H.M.S. *Dolphin*.

Commander Kenneth Howard Mills, R.N., who is married with three children, has the Starboard Watch, and Commander Robin Heath, who is married with two children, the Port Watch.

The last great ship of the Royal Navy to bear the same name was the battle-cruiser H.M.S. *Renown*, 32,000 tons, which was completed in 1916. Armed with six 15-inch guns she joined the 1st Battlecruiser Squadron of the Grand Fleet in 1917.

During the inter-war years, she took the then Prince of Wales on his world tour from 1920-1922.

In the last war the *Renown* took part in many famous actions, against the *Gneisenau* and *Scharnhorst*, in the Mediterranean with Force H, and was again in the action which resulted in the destruction of the *Bismarck*. The *Renown* was scrapped at Devonport in 1948.

There were eight previous ships to bear this famous name, the first being a 10-gun fireship which was captured from the Dutch in 1652.

FIELD LEAKAGE FROM COAXIAL CABLES

FROM D.C. TO A FEW MHz

H. Salt, B.Sc., R.N.S.S.
Admiralty Surface Weapons Establishment

Introduction

Associated with the flow of energy along a coaxial cable is a conduction current in the conductors and an electro-magnetic field principally in the dielectric between them. As a consequence of the finite conductivity of all electrical conductors, the field is not wholly confined to the region between the conductors but extends into the space surrounding the cable. Since the field does exist outside the cable, the transmission of electromagnetic energy along the cable can cause interference in nearby sensitive electronic equipment and can also lead to an unwanted transfer of energy from one cable to another one nearby.

There are many installations where several different types of equipments have to be situated relatively close together and their various cables cannot be well separated. It therefore becomes necessary to consider the electromagnetic screening properties of coaxial cables and to devise, if possible, a measuring technique so that cables may be compared. In normal use a coaxial cable is excited between the inner and outer conductors and there are three components of the electromagnetic field along the cable, namely the radial electric, the longitudinal electric due to the finite conductivity of the conductors, and the circular magnetic components.

In principle, one could excite the cable and couple to any of these three components outside the cable to obtain information on the field leakage, but if cables are to be compared, one must ensure that the measuring system couples only to the field due to leakage from the cable and not to fields from any other source. Also, since it is preferable to work in the laboratory, the test system must be of a reasonable size which in turn requires that the field strength inside the cable is as high as possible. These considerations effectively prevent one using a test system designed to couple to the radial electric or circular magnetic components but do not prevent the longitudinal electric component being used.

Since the test system is to couple with the longitudinal component, it will be convenient to determine the surface transfer impedance of the cable so that different cables may be easily compared.

If the cable provides the only paths along which conduction currents can flow across a plane cutting the cable and perpendicular to it, then the surface transfer impedance of the cable is defined as the ratio of the longitudinal component of the electric field on the outer surface of the outer conductor of the coaxial cable at the plane cutting it, to the current flowing across the plane along the centre conductor[1]. Hence, when comparing two cables, the one with the higher value of surface transfer impedance at any particular frequency is the cable which permits a higher value of the electric field along its outer surface and therefore has poorer shielding properties.

One must consider whether a measurement of the longitudinal electric component of the field on the surface of the outer conductor does in fact give a proper indication of the leakage of the complete field. The first point to note is that in passing from one medium to another, components of the electromagnetic field that are tangential to the boundary are in no way disturbed when crossing the boundary. Hence the value of the longitudinal component measured is also its value in the medium immediately adjacent to the conductor; air or a plastic usually. The second point to note is that in any one medium, the electromagnetic field components are related by Maxwell's equa-

tions through the physieal properties of that medium alone. This means that, having determined one field component in the medium surrounding the cable, the other two components ean be ealeulated using only the physieal properties of the medium with no further referenee to the eable. Henee, a determination of the surfaee transfer impedanee of a eable does give a true indieation of the field leakage from the eable.

A point of interest is the reciproeity of surfaee transfer impedanee. A given current flow along the eentre eonduetor gives rise to a longitudinal electric field on the outer surfaee of the cable sheath equal to the surfaee transfer impedanee of the eable multiplied by the value of this eurrent; if the eable sheath forms another line with a eoaxial eonduetor outside the eable, then if the same given eurrent were to flow along this further eoaxial eonduetor then the same longitudinal eleetrie field would appear on the inner surfaee of the eable sheath. In praetiee this outer eonduetor need not be eoaxial providing there is tight eoupling between it and the eable[2], as for example when two eoaxial eables are run together or a eable is run on ehannel plate.

The Testing Arrangement

The means of eoupling to the longitudinal eomponent of the eleetrie field on the surfaee of the outer eonduetor is shown in Fig. 1. The tester, known as a triaxial tester, is simply a eondueting tube eoaxial with the sample.

At the input end, the eopper disc of the sample is held in the tester by a brass serew elamp. Optimum eontaet between the eopper dise and the tester is required at the inner surfaee of the tester whieh is slightly eut baek in the elamp away from the inner surfaee of the tester so that as the clamp is serewed tight, maximum pressure is applied to the copper disc at this inner surface.

At the output end the diameter of the tester is abruptly redueed in size to fit a *BNC* soeket. This abrupt ehange is of no eonsequenee at the frequeneies eoneerned in the experiments earried out. The eentre eonduetor of the coaxial sample is carried on from the shorting plate of the sample to the eentre of this *BNC* output soeket. It ean be shown that[3] the voltage measured at this output is the voltage along the outer surfaee of the sample from the shorting plate to the eopper dise 30·48 em baek.

The tester has a wall thiekness of 1·09 em whieh eorresponds to one skin depth at a frequeney of approximately 37 eyeles per seeond, and three skin depths at approximately 300 e/s. This means that at 300 e/s the eurrent flow along the outer surfaee of the tester is approximately −26 dB, relative to that along the inner surfaee and ean reasonably be

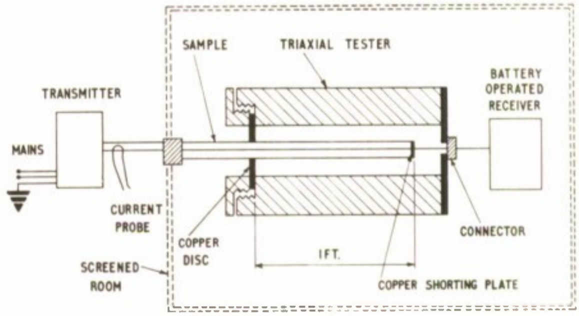


FIG. 1. Experimental arrangement.

negleeted. This does of eourse improve eonsiderably with increasing frequeney and at 900 c/s the eurrent on the outer surfaee is approximately −44 dB that along the inner surfaee.

The reeeiver and the tester are inside a sereened room to prevent direet eoupling with the transmitter and to reduee interferenee. It will be noted from Fig. 1 that the system is earthed only at the transmitter; this is to prevent earth-loop eurrents whieh eaused unexpectedly high output voltage readings when the system was being developed. This single point earth system was found to be the only way of preventing these eurrents. The eans on the two ends of the triaxial tester shown in Figs. 9 and 10 are made of eopper and are an additional preeaution against interferenee. The polythene spaeers for ensuring the samples and tester are eoaxial ean also be seen in Fig. 10.

The transmitters used eould deliver approximately 1 amp into the sample under test, whieh is almost a true short eireuit aeross transmitter over the frequeney range of the experiments. Up to 50 Kc/s a tuned receiver capable of detecting 0·1 μV was used but above 50 Ke/s the receiver available had a limit of 1·3 μV.

The Samples

The following expression has been derived for the modulus of surfaee transfer impedanee Z of a eoaxial eable[1].

$$|Z| = \frac{R_0\,x}{\sqrt{\cosh x - \cos x}}$$

where R_0 is the d.e. resistance the cable sheath (outer eonduetor) and

$$x = \frac{2t\sqrt{\pi \mu_0 \mu_p f}}{\rho}$$

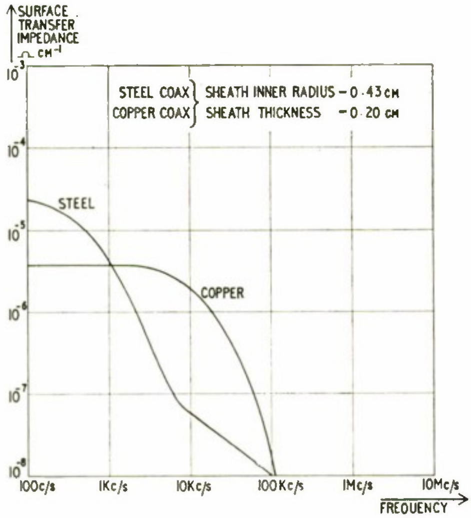


FIG. 2.

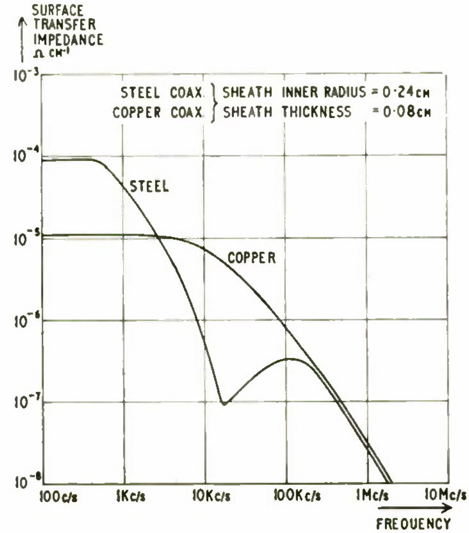


FIG. 4.

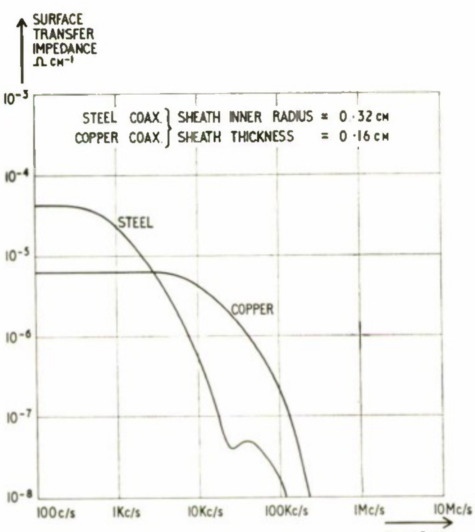


FIG. 3.

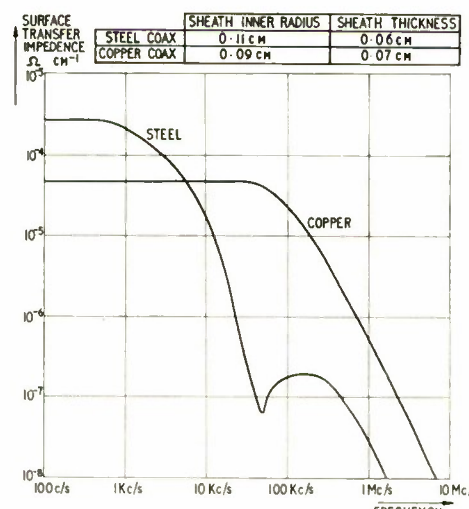


FIG. 5.

where t = thickness of the cable sheath

μ_o = permeability of free space

μ_p = relative permeability of the material of the cable sheath

f = frequency

where ρ = resistivity

A comprehensive analysis of this expression has been carried out to find the variation of surface transfer impedance with frequency, sheath internal diameter, sheath thickness and sheath material(4). In particular, the analysis was performed to see what advantages could be gained by using steel sheathed cables instead of the more usual copper or aluminium, and it was naturally decided that the first task of the tester should be to confirm the results of this theoretical analysis. The simplest and least expensive way of doing this was to purchase commercial mild steel and copper tubes of different diameters and thicknesses and to turn these into pairs of coaxial samples. This meant that the internal diameter and thickness of the samples

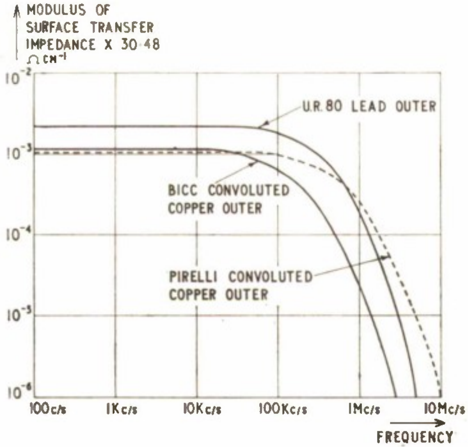


FIG. 6.

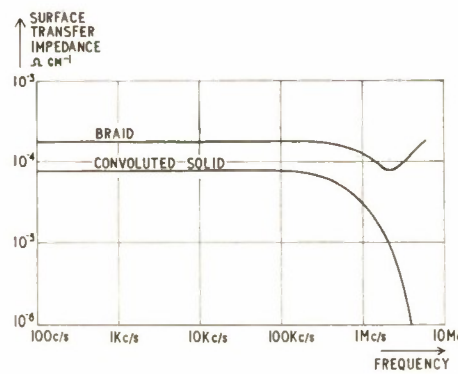


FIG. 7.

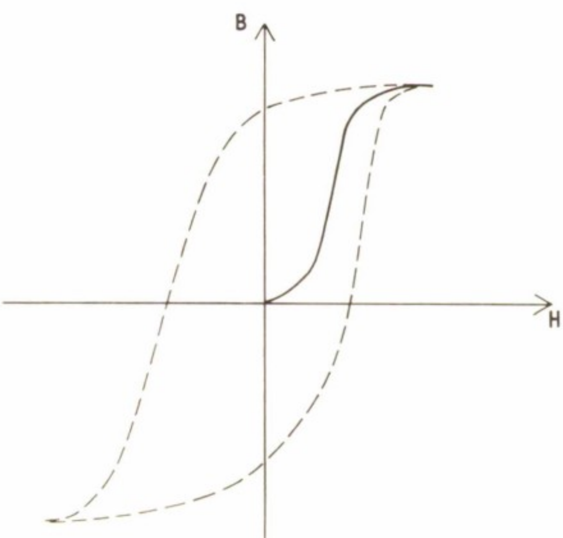


FIG. 8.

varied together and not independently. However the major requirement for these samples was to be able to observe and compare the shape of the curves of surface transfer impedance against frequency for identical steel and copper samples.

Details of the tubes selected for testing are shown below:

Material	*Tube Internal Radius*	*Tube Wall Thickness*
Copper; Mild Steel	0·43 cm	0·20 cm
Copper; Mild Steel	0·32 cm	0·16 cm
Copper; Mild Steel	0·24 cm	0·08 cm
Copper	0·09 cm	0·07 cm
Mild Steel	0·11 cm	0·06 cm

The tubes were approximately 39 cm long and were formed into coaxial samples by soldering a copper shorting plate of the same thickness as the tube wall into one end, soldering a copper disc on to the outer surface 30·48 cm (12 in.) from the shorting plate and passing a copper wire down the tube through a central hole in the shorting plate. The copper wire diameter was chosen so as to make the characteristic impedance of the so-formed coaxial sample as near to 50 ohms as possible. A suitable coaxial plug (*BNC* or *UHF*83) was then soldered on to the open end. In the case of the smallest copper and steel samples, the centre conductor was a miniature coaxial cable from which the braid had been removed. The shorting plate then took the form of a blob of solder and the plugs used for these samples were miniature *BNC*.

The form of the samples ready for fitting into the tester can be seen in Fig. 10. It will be noticed from Figs. 9 and 10 that the *BNC* output socket on the tester, on the right hand side of these figures, is not in the position shown in Fig. 1. This is because it was originally intended to fit a wide-band amplifier on a card at the output end of the tester and to feed this amplified output into an r.f. voltmeter. The supports for the card can be seen in Fig. 8 but the required sensitivity prevented the use of a wideband system and the card shown is a direct feed-through card.

The tester has been used to measure the variation with frequency of the surface transfer impedances of several cables.

Results

Figs. 2, 3, 4 and 5 show the curves obtained for the pairs of steel and copper tubes. All these curves agree with the results of the theoretical analysis mentioned earlier[4], namely, the curves are initially flat and equal to the D.C. resistance of the sample sheath; the frequency at which the surface transfer impedance starts falling increases as

the thickness is decreased; the curves for the steel samples cross those for similar copper samples on the straight horizontal portions of the copper curves.

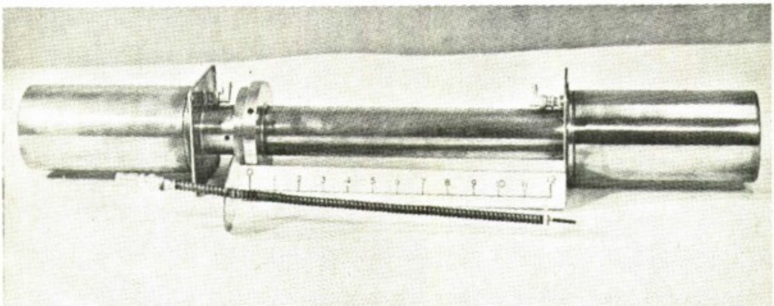
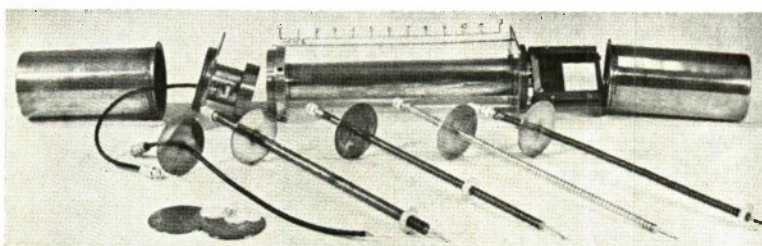


FIG. 9.

Several cables have been tested but Figs. 6 and 7 are sufficient to illustrate the use of the tester. Fig. 6 shows the comparison of the lead sheathed *U.R.*80 and the two convoluted copper sheathed cables made by BICC and Pirelli. Fig. 7 gives the comparison between the braided *U.R.*70 and the one with the solid convoluted copper sheath.

It is to be noted that the minimum values of surface transfer impedance recorded lie in the lowest decade shown (10^{-8} ohm cm^{-1}) and the curves have been extrapolated to the limit.

FIG. 10.



Discussion

Steel and Copper Tube Samples

The fact that the surface transfer impedance of a steel sample decreases at a much lower frequency than the corresponding copper sample is due to the higher value of permeability for steel than copper. However the relative permeability of steel decreases at increasingly high frequencies and does in fact fall to unity at some high frequency thus causing the curve for a steel sample to cross that for a copper sample once again. However, down to the limit of the measurement (10^{-8} ohm cm^{-1}), no second crossing point is found in the experimental curves shown This is not surprising since the frequencies used are all less than 1 Mc/s and from the published data on the variation of the relative permeability of iron with frequency one would expect a second crossing point to be well into the megacycle region. However, the Figs. 4 and 5 would lead one to expect that with some mild steels a second crossover point would be found at frequencies less than 1 Mc/s.

Permeability of Steel Samples

The tests were carried out inside a steel screened room so that the effects of the earth's magnetic field may be neglected. The fact that the curves for the three smaller steel samples rise in the frequency range 10 Kc/s to 100 Kc/s is very interesting. It can be shown analytically[3] that this occurs when the relative permeability of the steel decreases very rapidly with increasing frequency. Above 100 Kc/s the permeability appears not to change at all.

For an explanation of this rapid change in permeability one may consider the shape of the B-H curve as shown in Fig. 8 and in particular the full curve obtained when increasing the applied field H from zero. Remembering that by definition permeability μ is equal to $\frac{B}{H}$, it can be seen that the only region where the permeability changes rapidly is in passing from the essentially straight part through the origin, or " toe " of the curve, to the steep essentially straight part or " instep " of the curve. Present day theories of ferromagnetism consider the crystal lattice of the material to be broken into domains, inside of which all the atomic magnetic dipoles are aligned, so that in any one domain the material is magnetically saturated in some direction. The boundaries between the domains are known as Bloch walls When a small field is applied, the domains in which the dipoles are most nearly aligned with the applied field expand at the expense of their neighbours, that is, there is a Bloch wall movement through the lattice. This corresponds to the initial part of the B-H curve through the origin

and since this wall movement is reversible, so is this part of the curve. As the field is increased, the walls move past discontinuities in the lattice giving rise to the steep part of the curve and irreversibility. When a wall moves across a discontinuity it is said to make a Barkhausen jump.

It is obviously relevant to consider the magnetic field strength at the inner surface of the steel sheaths of the samples, and this can be found using Amperes theorem, as shown below:

Internal Radius of Sheath of Sample " r "	*Current I*	*Magnetic Field Strength at Inner Surface of Sample Sheath* $H = \frac{I}{2}$
$4{\cdot}3 \times 10^{-3}$ m	1 amp	$3{\cdot}71 \times 10^{2}$ A-turn . m^{-1}
$3{\cdot}2 \times 10^{-3}$ m	1 amp	$4{\cdot}97 \times 10^{2}$ A-turn . m^{-1}
$2{\cdot}4 \times 10^{-3}$ m	1 amp	$6{\cdot}63 \times 10^{2}$ A-turn . m^{-1}
$1{\cdot}1 \times 10^{-3}$ m	1 amp	$1{\cdot}45 \times 10^{3}$ A-turn . m^{-1}

All the above field strengths are of the order of magnitude sufficient for the permeability to be given by the instep region of the B-H curve. However, it would appear that between 10^4 c/s and 10^5 c/s the applied field is not acting for a sufficiently long time for the Bloch walls to move across the discontinuities in the lattices of the crystals of the sample so that the permeability of the sample falls from its high value at the instep to the lower value at the toe, known as the initial permeability. It has been shown by Döring[(5)] that a wall in motion has a considerably greater energy than when at rest and that because angular momentum is associated with the atomic spins in the Bloch wall, the wall behaves as if it had a mass inertia which could account for the seemingly low speed of the wall. A detailed study of the possible effects of lattice discontinuities on the mass inertia associated with the Bloch wall might allow surface transfer impedance measurements to yield information on domains in steel tubes.

Energy considerations agree with the above reasoning. A higher value of surface transfer impedance means that the field strength outside the sample is higher; the vector cross product of the longitudinal component of the electric field and the circular magnetic field gives the energy flow normal to the surface of the sheath, so that if the surface transfer impedance increases with frequency, then the energy absorbed in the sheath decreases with frequency. Remembering that the area within the hysteresis loop is the energy absorbed magnetically and that a minor loop is of course traversed each cycle, then when the surface transfer impedance increases, the areas of the minor loops successively being traversed must be decreasing with frequency which can only happen if the Bloch walls pass through fewer discontinuities and the permeability falls towards its initial value.

It should be remembered of course that if a steel sheathed coaxial cable were used in practice, the current flow would be much smaller than that used in these tests so that the initial permeability of the steel would be the relevant permeability. The surface transfer impedance against frequency curve for this case can be found from the present curves merely by extrapolating the lower straight portion back to the D.C. resistance level. Fig. 4 in particular illustrates that if the use of a mild steel coaxial cable for screening purposes were being considered, then it would be necessary to be somewhat more specific about the mild steel used for the cable sheath than the arbitrary choice made for these tests. Since tension has a marked effect on permeability it would also be necessary to consider any effects produced in manufacture of the cable.

U.R.80 Lead Sheathed Cable, BICC and Pirelli Convoluted Copper Sheathed Cables

Uniradio 80 was chosen for this comparison because a length was immediately available and it has the same sheath thickness as the more commonly used *U.R.*45 lead sheathed cable. Fig. 6 clearly shows how the triaxial tester may be used to compare the screening properties of different cables. Since the initial flat portions of the curves for the BICC and Pirelli cables have approximately the same value, the D.C. resistance per unit length of the sheaths of these cables are approximately the same, whereas that of the lead cable is about twice as large which means that the leakage from the lead cable is about twice that of the copper cables. The fact that the surface transfer impedance of the BICC cable falls at a lower frequency than that for the Pirelli cable indicates that the effective thickness of the BICC cable is greater than that of the Pirelli one. The term effective thickness is being used here to cover any variations along the length of the cable due to the convolutions.

At the higher frequencies the Pirelli cable permits the greatest field leakage and the BICC cable permits the least. Comparing the lead and BICC cables, at 100 Kc/s the BICC provides about 8 dB better shielding and at 1 Mc/s about 20 dB better shielding. For the Pirelli cable to afford the same shielding as the BICC cable at the higher frequencies, the effective thickness of the sheath of the Pirelli cable would need to be approximately twice its present value.

U.R.70 Braided Copper Sheath and Solid Convulated Copper Sheath

The braided cable allows about twice as much field leakage as the solid sheathed cable at the lower frequencies and about five times as much at 1 Mc/s. The most interesting point to note about Fig. 9 is that the surface transfer impedance for the braided cable increases above 2 Mc/s. Measurements up to 70 Mc/s, not shown on this figure, indicate that the surface transfer impedance of a braided *U.R.*70 cable continues to rise above 2 Mc/s.

Conclusions

A convenient testing system has been developed to compare the relative screening merits of different coaxial cables.

The frequency range over which a copper sheathed coaxial cable permits detectable leakage and a mild steel sheathed cable does not, is very limited and depends on the particular mild steel. Since at lower frequencies, a steel sheathed cable has a much higher value of surface transfer impedance, it would allow for more low frequency interference, than would a copper sheathed cable; this is important since power frequencies are low. These two points lead to the conclusion that a copper sheathed coaxial cable is to be preferred to a steel sheathed coaxial cable.

The results of triaxial measurements with steel tubes could possibly be used to give information on the magnetic domains in the steel and the movement of Bloch walls. This could be useful since the strains in a tube must tend to lie in one direction, the particular direction depending on whether the tube has been bored or drawn.

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(5) Inertia of Walls between Weiss Domains. W. Z. Döring. *Naturforsch*, **3a** (1948) 373-9.

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REPLACEMENT FOR ICE PATROL SHIP

The Navy Department of the Ministry of Defence has purchased from J. Lauritzen Lines, Copenhagen, the ten-year-old *Anita Dan*, a ship strengthened for operation in ice, for conversion and use as an ice patrol ship in southern waters. She will eventually take the place of H.M.S. *Protector*, a converted netlayer, which has, for many years, been operating in the South Atlantic and Antarctic areas.

H.M.S. *Protector* was built in 1936 and is nearing the end of her life. Studies have been undertaken into the most economical way of providing a suitable replacement. One possibility, that of building a new icebreaker, was found to be too expensive. A second, that of building a new survey vessel and strengthening her hull for operation in the ice, was also considered to be unnecessarily costly in terms of money and design effort for a one-off ship.

The chosen plan is based on taking an existing, purpose-built ship—the *Anita Dan*; retaining many of her commercial features and equipment; but converting her as necessary to provide increased accommodation, naval communications and equipment, and the ability to operate helicopters. Her refit and conversion, which will be responsible for the greater part of the overall cost of providing the new ship, will be undertaken at a suitable British commercial shipyard.

When completed, *Anita Dan*, which is 300 feet long, and 2,641 gross tonnage, will enter the active fleet (and may well be re-named) and will embark two Whirlwind helicopters and, like *Protector* before her, will be deployed in southern waters undertaking hydrographic and oceanographic surveys for the Royal Navy, and continuing to support the activities of the British Antarctic Survey Group. She will, however, have a smaller crew than *Protector's* and will not be so costly to run and maintain.

A REVIEW OF AUTOMATIC PATTERN RECOGNITION

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SUMMARY

The automatic recognition of patterns such as printed letters, spoken words and photographic data is an important and interesting new field with many potential applications. Some of the basic principles are reviewed in this article and illustrated from published work.

Introduction

The possibility of automating some of the routine and time consuming pattern recognition tasks normally carried out by trained observers, has attracted a good deal of attention in recent years. The patterns may be spatial ones such as printed letters and numbers or they may involve the time dimension, as with spoken words. For a given set of pattern classes, the basic problem is to design a process which allows unknown patterns from the set to be classified automatically from their measured properties and a knowledge of the statistics of the set. Digital computers provide a convenient tool for design and development studies of this kind.

Some interesting examples of automatic pattern recognition work are the transcription of printed and hand written characters into machine readable codes, the recognition of weather patterns and the identification of photographically recorded data such as cancer cells, chromosomes, fingerprints and elementary particle tracks. Pattern recognition is also an important concept in work on artificial intelligence.

Interest in the subject at AUWE is in application of the techniques to the recognition of sonar echoes from a confusion of background events. Other possibilities relevant to the work of the RNSS are the classification of acoustic noise patterns radiated by ships, speech recognition and the detection of radar echoes.

A complete review of the many aspects of automatic pattern recognition is beyond the scope of this article and the aim here is to outline the design principles common to most recognition problems. Examples from some of the published work on character and speech recognition are then used to illustrate typical applications of these basic principles.

Design Principles

The design of successful automatic pattern recognisers is much more difficult than would appear from the ease with which human observers classify patterns. Patterns generally show considerable variability within classes due to a combination of noise-like effects and inherent variations—the possible ways of writing a letter or saying a word for example—and distinctions between classes are not always obvious. For this reason, deterministic classification solutions are rarely feasible and the theory of pattern recognition is essentially that of probability and statistics.

The basic approach to the design problem considered in the following sections, is to derive statistical data and classification rules from samples of patterns of known identity. The design is then tested with an independent set of known patterns and if an acceptable level of performance is achieved, the machine may be used to classify unknown patterns automatically. This approach can usefully be considered under four headings.

a. Input devices for sensing the patterns
b. Measurements describing the patterns and pattern statistics
c. Decision rules for classifying patterns
d. Testing procedures

In any practical design problem there are, of course, various constraints such as economic feasibility, the possible need for operation in real time, limitations on the amount of pattern data available and so on. There will also be considerable feedback between the four design stages and

for this reason, feasibility or research studies are often carried out by simulation techniques using a digital computer. Special purpose hardware, other than that needed for sensing the patterns, is only likely to be introduced when a design is finalised and is not discusssed in this review.

Input Devices

The choice of pattern sensing transducers is usually straightforward although it depends very much upon the particular application. In speech recognition a microphone and spectrum analyser may be used to convert the acoustic waveform into a binary pattern, the I's and O's of the pattern corresponding to the presence and absence of particular frequency bands as a function of time. Magnetic scanning units are sometimes used in printed character recognition but are usually limited to specialised applications such as automatic cheque sorting, where magnetic inks and special printing founts can be conveniently used.

Optical scanning methods are used with photographed patterns and in many character recognition applications. Methods vary from simple rotating disc systems with a single photocell to whole arrays of photocells but the flying spot scanner is perhaps the most economical method of obtaining reasonable speeds and resolution. The principle is to focus light emitted from the spot on the face of a cathode ray tube on to the pattern as the electron beam scans across the tube face. The amount of light transmitted (or reflected) by the pattern is measured by a photomultiplier at a number of known points during a scan. In this way the pattern is represented by a discrete matrix of transmitted or reflected intensities. Ward and McMaster(1) have recently described an advanced form of flying spot scanner having a resolution variable from 16 to 125,000 points for use with 35 mm. transparencies. The photomultiplier output at each point is represented on a digital scale of 0 to 128. This particular scanner is being used at the University of Strathclyde to study the differences between normal cells and cancer cells but is suitable for use with almost any sort of photographed pattern.

Measurement Space and Pattern Statistics

Any pattern may be described by a set of N measurements $(x_1, x_2 \ldots x_N)$ and may be thought of as a point in an N dimensional measurement space, each class having a certain probability distribution on its members. The pattern recognition problem arises if these distributions overlap in the sense that it is not always certain to which class an unlabelled point belongs. The object is to classify such patterns in an optimum way—by minimising the total recognition error for example.

The input measurement space obtained, say, from a high resolution flying spot scanner, contains a great deal of information about the patterns under study but the dimensions of the space are usually too large to allow a feasible classification procedure to be derived. The designer must either make some simplifying assumptions about the functional form of the pattern measurements or must look for a transformation of the input space which reduces the dimensions to the minimum necessary for an adequate classification solution. The choice of a suitable set of measurements or properties with which to represent the input patterns is one of the outstanding problems in pattern recognition work.

It would often be helpful if the properties used by human observers in recognising particular patterns could be defined but this seldom seems to be possible, although current work on the psychological aspects of pattern recognition may eventually prove useful in this respect.

Methods have been proposed for evaluating the "goodness" of selected measurements by a preliminary set of experiments but their application is restricted by the simplifying assumption of statistically independent measurements.

In practice, the initial selection of measurements must usually be left to the designer's intuition, based on a careful study of available patterns and guided by a few obvious rules—a statistically sufficient description of the patterns is required and the measurements should exploit differences between classes whilst being insensitive to variations within classes. For spatial patterns, this usually means looking for properties which are substantially invariant under translation, rotation and scale changes. The design of the input transducer and the choice of decision procedure may also influence (or be influenced by) the number and complexity of the properties that can be used.

Having defined a measurement space, representative samples of the pattern classes are needed to provide a statistical basis for the decision rule. Functional forms may be known or guessed for the distributions of pattern measurements, in which case pattern samples are required to estimate the distribution parameters. If functional forms are not known they may either be estimated from the samples or representative values of the distribution stored in the computer.

Decision Rules

A variety of methods are available for making classification decisions. In simple pattern recognition problems some sort of normalisation followed by a matching against prototype versions of the possible classes may be adequate. The matching criterion may be a cross correlation

between the unknown pattern and the average of known members of a class. However, if the pattern distributions show appreciable spread and overlap due to inherent variations and noise, such methods may no longer lead to acceptable classification errors. Statistical decision theory provides a general approach to the classification problem.

Statistical Decision Theory

Statistical decision theory is an extension of the ideas of hypothesis testing to include the prior probabilities of the classes and the costs associated with the possible decisions. The optimum decision may be defined as the classification which minimises the average loss due to the costs of misrecognition—the so called Bayes Procedure.

The theory has been widely applied to the binary decision problem of detecting signals in noise[2]. Signal detection can, in fact, be regarded as a special case of pattern recognition in which the pattern is a sampled representation of the observed waveform and the recognition process consists of assigning the observed pattern to the class of signal plus noise or noise alone. Signal processing theory has however developed as a separate subject, possibly because the problems are more amenable to functional analysis.

The basic result of decision theory for the two class case is a division of the measurement space into regions R1 and R2 such that the average loss is as small as possible. Specifically, if $P_1(X)$ is the probability distribution for Class 1 and $P_2(X)$ for Class 2, if P_1 and P_2 are the respective prior probabilities, C(2/1) the cost of classifying an observation as from Class 2 when it is actually from Class 1 and *vice versa* for C(1/2), then the decision rule is to assign the observation X to R1 if

$$\frac{P_1(X)}{P_2(X)} \geqslant \frac{C(1/2)}{C(2/1)} \frac{P_2}{P_1} \quad \ldots (1)$$

P_1 (X) and P_2 (X) can be obtained experimentally by measuring the distributions of X for known members of the two classes. The prior probabilities for the two classes may sometimes be known but values are more often allocated arbitrarily or based on subjective estimates. The cost factors may be assigned on a relative basis with the cost of correct decisions taken as zero. C(1/2) and C(2/1) may, for example, be the cost of identifying a malignant cancer cell as a normal cell and *vice versa.* The cost of the first error is clearly higher than that of the second. On the other hand, in this example, the prior probability of the class of cancer cells is presumably much lower than that of the class of normal cells.

All the well known criteria of hypothesis testing are special cases of Equation 1 for particular assignments of costs and prior probabilities. For example, if costs are equal, the decision rule is to choose the region with maximum *a posteriori* probability (*i.e.* to minimise the average probability of misclassification). If prior probabilities are also equal, the maximum likelihood criterion is obtained. The important point is that application of Equation 1 is based upon a calculation of the likelihood ratio $L=\frac{P_1(X)}{P_2(X)}$ and comparison with a decision threshold $K=\frac{C(1/2)}{C(2/1)} \frac{P_2}{P_1}$

If P_1 (X) and P_2 (X) are multivariate normal distributions of the form $P(X)=\frac{1}{(2\pi)^{\frac{N}{2}} |A|^{\frac{1}{2}}}$

$$\exp\left[-\tfrac{1}{2}(X-M)^1 A^{-1}(X-M)\right]$$

where A is the covariance matrix for the distribution parameters, N is the number of components of the vector X and M is the vector of component means.

then, taking the logarithm of P(X), gives an expression of the form

$$\log P(X)=-\tfrac{1}{2}(X-M)^1\ A^{-1}\ (X-M)+\text{constant} \quad \ldots (2)$$

The decision surface defined by $\frac{P_1(X)}{P_2(X)}=K$ is therefore a quadratic function of X—a so-called hyperquadric in the N dimensional measurement space.

If the covariance matrices for P_1 (X) and P_2 (X) are equal, the boundary is a hyperplane of the form

$$X^1\ A^{-1}\ (M_1-M_2)=\text{constant} \quad \ldots (3)$$

Pattern recognition usually involves a number of classes and a more general expression than Equation 1 is needed[3]. A division of measurement space into m regions $R_1, R_2 \ldots R_m$ is required such that if an observation appears in region R_i it is said to belong to the i^{th} class. If the cost of mis-classifying an observation from i as from j is C(j/i), if P_i is the prior probability of the i^{th} class and P_i (X) the probability of X given the i^{th} class, then the decision rule which minimises the average loss is to choose the region R_k if

$$\sum_{\substack{i=1\\ i\neq k}}^{m} P_i\ P_i\ (X)\ \ C(k/i) < \sum_{\substack{i=1\\ i\neq j}}^{m} P_i\ P_i\ (X)\ \ C(j/i) \quad \ldots (4)$$

$$\text{For } j=1, 2 \ldots m \;\; j \neq k$$

Fig. 1 illustrates the application of this rule. The input measurement X is first used to calculate

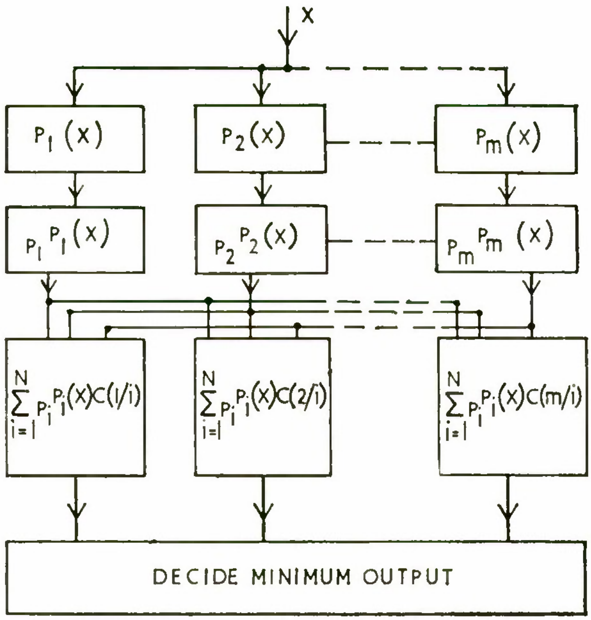

FIG. 1. Minimum loss decision rule.

the conditional probabilities P_i (X) for each possible class. These are then weighted by their prior probabilities P_i and the third stage weights each of these with the appropriate cost factors and forms the sums ($C(j/j=C(k/k)=0$ is assumed here). Finally the decision stage examines all the inputs, selects the smallest one and assigns the observed pattern X to the corresponding class.

The idea of a rejection class is frequently introduced into practical problems by defining regions around the decision boundaries in which observations are rejected, since it is often better to reject a pattern than to risk mis-classification.

If costs are equal, Equation 2 reduces to choosing R_k if

$$P_k \, P_k \, (X) > P_j \, P_j \, (X) \text{ for all } j \neq k \quad \ldots \quad (5)$$

i.e. the maximum *a posteriori* probability rule.

One of the difficulties in implementing decision theory rules is that prior probabilities and costs are not always known with any certainty. In printed character recognition for example, the prior probabilities of the letters can be estimated but the cost of misrecognition is more difficult to establish although clearly some errors will be more serious than others. The simplifying assumption of equal costs is often made in such cases leading to a minimisation of the average error rate. Prior probabilities are also frequently assumed to be equal if unknown although whether or not this assumption can be justified is the subject of considerable philosophical argument.

The main difficulty, however, is that the likelihood function P_i (X) may be too complicated to estimate from available samples. If measurements are dependent and the dimensions of the measurement space are moderately large, the joint probability P_i ($x_1 \, x_2 \ldots x_N$) requires many samples to estimate the parameters of the distribution functions or a large amount of computer storage is needed if all possible states of the distribution are to be held in non-parametric form. The problem is simplified if the measurement space can be chosen to make the measurements statistically independent since then $P_i \; (X) = \prod_{j=1}^{N} P_i \; (X_j)$. Alternatively the dimensions of the measurement space may be reduced by rejecting the least discriminating measurements or by combining properties in some way.

The result of all this is that the decision theory solution (or any other solution) to a practical problem can be optimum only in a restricted sense *i.e.* within the limits imposed by the choice of measurement space, the representative nature of of the pattern samples used in the design, and assumptions about the form of the likelihood functions, the cost factors and prior probabilities. Fortunately, the overall validity of such assumptions can be tested by using the design to identify patterns whose classifications are known independently.

Linear Methods

The practical difficulties often associated with a direct application of statistical decision theory to multidimensional pattern recognition problems has inevitably led a number of workers to study the possibilities of linear methods. This approach leads to solutions which can be implemented by quite simple analogue circuitry ~~but~~ optimisation is further restricted to the class of linear decision functions.

The theory of classification by linear discriminant functions has received some attention in classical statistics and has been applied to such fascinating problems as the classification of Eygptian skulls into dynasties and the identification of plant species. The basis of the method described by R. A. Fisher[4] is to choose a linear function of the measurements, $X = \sum_{i=1}^{N} a_i \; x_i$, which is optimum in the sense that it maximises the square of the difference between the mean X's for the two classes divided by the variance of X (assumed common to both classes). Samples of known classification are used to obtain the values of the N coefficients satisfying this maximisation. An unknown pattern is classified by calculating X

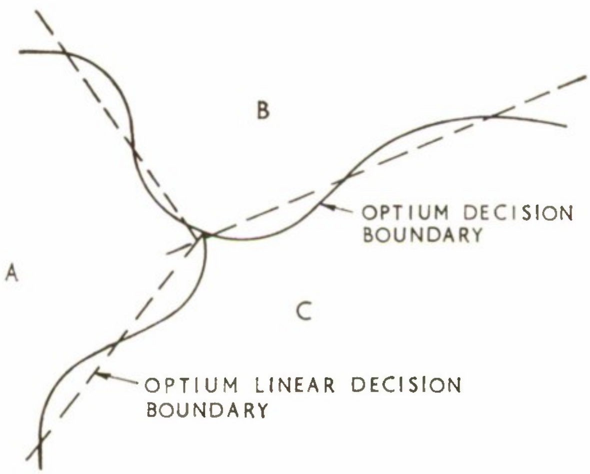

FIG. 2. Linear decision boundaries.

and assigning the pattern to the class with the nearest mean value of X. Geometrically, the linear discriminant defines the direction in N space in which classes are most separable. The result turns out to be identical, except for a constant term, to the decision theory solution for multivariate, normal distributions with equal covariance matrices in Equation 3.

The application of linear methods to automatic pattern recognition problems has been described more recently by Highleyman[5]. Decision theory gives an optimum division of the measurement space by surfaces defined by $\frac{P_1(X)}{P_2(X)} = K$ where K is a constant depending on the costs of misclassification and the prior probabilities. The points X in measurement space which satisfy this relationship lie on the decision boundary which will, in general, be a curved surface. The object of Highleyman's method is to find a plane surface (or hyperplane) of the form $\sum_{i=1}^{N} a_i x_i =$ constant which is the best fit to the more general decision surface. Fig. 2 illustrates this idea for three classes in two dimensional measurement space.

The number of hyperplanes required to completely classify N categories is $\frac{N(N-1)}{2}$, although in practice all the hyperplanes may not be needed. It may be possible, for example, to use just N hyperplanes each dividing one class from all the others. Alternatively the measurement space may be first divided into two subsets by a single boundary and the classes of the subsets separated by complete linear functions. A possible example is in character recognition where an initial classification into letters formed only from straight lines and those formed only from curves might usefully be made.

A completely rigorous solution requires all boundaries to be determined simultaneously, since each boundary influences the others but such a solution is unmanageable with even a moderate number of classes and hyperplanes are usually computed independently for each pair of classes. Highleyman gives an analytical solution for the case where prior probabilities and the probability density functions are known. He also describes a method of computing the optimum hyperplane when these probabilities are unknown. If B_{ij} is a hyperplane which divides the patterns of the i^{th} and j^{th} classes in some arbitrary fashion, then the conditional loss associated with the boundary B_{ij} when patterns are chosen randomly from classes i and j is

$$C(B_{ij}) = c_{ij}\, e_i + c_{ji}\, e_i \qquad \ldots (6)$$

where e_i is the probability of misrecognition of a sample from class i and e_j for class j, given B_{ij}. The cost associated with confusing a sample from i with one from j is c_{ij}. An iterative method, based on the method of steepest descent, is then used to compute the hyperplane which minimises the loss.

Once the decision boundaries are found, a new pattern may be classified by assigning it to the i^{th} class if it is on the i^{th} side of all hyperplanes B_{ij}, $1 \leqslant j \leqslant m$, $j \neq i$, m=number of classes. If a hyperplane is represented by a set of points satisfying $\sum_{i=1}^{N} a_i x_i + a_0 = 0$ where $\sum_{i=1}^{N} a_i^2 = 1$, then a standard result of co-ordinate geometry is that the distance of a point with co-ordinates m_i from the hyperplane is $d = \sum_{i=1}^{N} a_i m_i + a_0$. Thus, once the hyperplanes are established using random sampling of patterns of known classification, the classification of an unknown pattern is made by substituting its co-ordinates into the nomalised expression for a hyperplane and the result is positive if the point lies on one side and negative if on the other.

Linear methods are only likely to be adequate if the classes to be separated are unimodal and form convex sets *i.e.* a line segment joining two points belonging to a set is contained within the set.

Other Methods

Sebestyen[6] has described a method in which a clustering transformation of the measurement space is derived for each class. The transformation is based on the sum of squares of the weighted distances between members of a class and the weights are chosen to minimise this sum, with the constraint that the volume of the space is held constant. The similarity between a new pattern and a class is given by the sum of the squares of the weighted distances between the point and each known member. Classification, in the two class case, is made by comparing the difference between the measures of similarity with a suitable threshold. Sebestyen shows that this method is identical to the decision theory result for multivariate normal distributions with different covariance matrices and in this sense it is more general than the linear discriminant function.

The sort of distributions shown in Fig. 3, even though mutually exclusive, could not be separated by a single linear boundary. Various non-linear techniques have been described[6] for dealing with such cases but their complexity is usually at variance with the search for methods which are economically feasible. If a more suitable description of the patterns cannot be found by transformation of the measurement space, then a simple proximity rule is sometimes adequate. The rule is to assign a pattern to class A if it is nearer to the nearest known member of A than to the nearest known member of any other class. The decision boundary is the locus of points equidistant from the nearest members of the two classes. The analytical expression of the rule is to decide X belongs to A if

$$\min_{\text{all } m}\left[\sum_{n=1}^{N}(x_n-a_{mn})^2\right]<\min_{\text{all } k}\left[\sum_{n=1}^{N}(x_n-b_{kn})^2\right]$$

where a_{mn} is the n^{th} co-ordinate of the m^{th} member of class A and b_{kn} is the n^{th} co-ordinate of the k^{th} member of class B.

The rule has obvious shortcomings, such as its sensitivity to odd samples although this can be avoided to some extent by introducing some sort of local majority factor.

Testing

It is clear from the previous sections that, although a useful theoretical framework exists for pattern recognition design, practical applications inevitably involve various assumptions and approximations. The choice of a suitable measurement space and decision rule is seldom obvious and there is a considerable element of trial and error in all but the simplest designs. Thorough testing of possible methods is therefore an important part of the design procedure. Error probabilities can be estimated from the proportions of misrecognised patterns observed during testing with independent samples of known classification. Random sampling of the known patterns is probably the safest way of testing a design although selective sampling might be used if the prior probabilities of the classes are accurately known. Highleyman has given methods of obtaining confidence limits for the measured error rates in terms of the number of samples used. The number of samples needed for a given level of significance can also be estimated and may be useful in cases where test patterns are difficult to obtain. Results are often presented graphically as the probability of correct recognition against probability of misclassification or false alarm (see Fig. 4). This is called the Receiver Operating Characteristic in signal processing work. Another

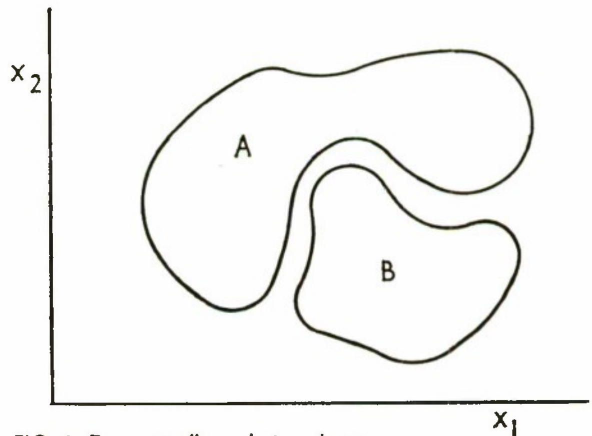

FIG. 3. Two mutually exclusive classes not separable by a linear boundary.

method frequently used is the "confusion matrix" presentation in which the number of correct and incorrect recognitions are tabulated for every class in the set. Fig. 5 for the decimal numbers 0 to 9 is an example (taken from Highleyman's paper). The diagonal, where each pattern class is compared with itself, gives the number of correct recognitions, all other entries correspond to misrecognitions. The column headed R gives the number of rejected patterns. The regions of confusion can be clearly seen from such a table.

As a result of the test programme, it may be possible to simplify the recognition process. If a linear decision function has been used, the least valuable measurements are those with the smallest coefficients. In the decision theory approach, measurements with similar probability distributions for two or more classes are the least useful and such measurements can be omitted. If the measured error rates are too high, the least useful

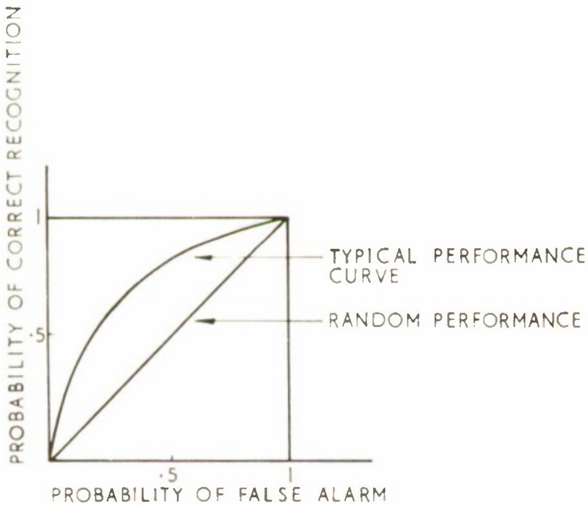

FIG. 4. Receiver operating characteristic.

measures may be replaced by new properties. Design and test programmes must obviously be flexible enough to allow such modifications to be readily made and evaluated.

Adaptive Systems

The design methods discussed so far involve numerical analysis of the available pattern data to derive distribution parameters or weighting factors. It is sometimes possible to carry out the design process by an adaptive training routine. An appropriate decision process must first be assumed, usually a weighted linear combination of the input measurements, and, starting from arbitrary values, the weighting factors are varied according to the machine classification of a sequence of known patterns. The process is controlled by the designer, who supplies the patterns, decides whether a correct response has occurred and initiates the weighting changes. For certain types of pattern distributions and with suitable error correcting procedures, convergence to an acceptable level of performance is possible. The resulting values of the weighting factors may then be incorporated into a special purpose machine.

This type of approach has received considerable attention in the wider context of artificial intelligence[7] where one of the problems is to design machines capable of quite general pattern recognition tasks. Networks of simple adaptive elements, somewhat analogous to neurons in the biological nervous system, are used and the input patterns may be sensed by a bank of photocells, simulating a retina. Connections between elements may be completely random but such networks are not always very efficient and the present trend seems to be towards more orderly arrangements. Such systems are general in the sense that the same network can be used for different recognition tasks after suitable periods of adaptive training, provided the pattern classes are linearly separable.

The best known adaptive elements are Widrow's Adaline (Adaptive Linear Neuron[8]) and Rosenblat's Perceptron[9]. Networks of Adaline's (Multi-Adalines or Madalines) have been used for simple weather forecasting, speech recognition and the diagnosis of heart disease from vector-cardiogram patterns and Perceptrons have been used for character recognition work.

The patterns available for training purposes may not always be representative of all future patterns, and cost functions may also vary with time. It seems logical therefore to continue the adaptive process after termination of the supervised stage. This is only possible by using the machine made classification decisions to update weights and thresholds in some way. There would seem to be a considerable danger of a drift towards increasing error rates in such a method and not much work has been reported on this aspect of adaption.

Any pattern recognition device must be based in some way on probability estimates derived from past experience and in this sense learning machines are just another way of applying decision theory. Whether or not they will provide the ultimate answer to automatic pattern recognition is a topic of some controversy but present opinion seems to be that conventional methods, tailored to specific applications, are likely to be more economical.

APPLICATIONS

Numerous practical applications of automatic pattern recognition techniques have been described in the literature and there is also a good deal of unpublished work in progress. It is not possible to give a representative survey here and the applications described in the following sections are simply chosen to illustrate some of the methods and problems discussed so far.

Character Recognition

A large proportion of pattern recognition work is concerned with the transcription of alphanumeric characters to computer readable codes. Feidelman[10] has given an up to date review of the machines commercially available in the U.S.A. It is interesting to note that all operate with special type founts and that only simple correlation methods are used. However, within these limits, results are quite impressive with low error rates and reading speeds of up to 2,000 characters/sec

RECOGNISED AS

INPUT CLASS	0	9	8	7	6	5	4	3	2	1	R
0	9										3
9		6		1			1				4
8	1		5					2		1	3
7		1		8			2				1
6					8	1					3
5	1					8		2			1
4		3			2		4				3
3						2		9			1
2				2	1				6		3
1										11	1

FIG. 5. Confusion matrix.

(but much less in practice because of paper transport problems). Banking applications use a limited set of numbers and symbols printed in magnetic ink. Character shapes are designed to give distinctive responses when scanned by magnetic read heads rather than for their legibility. Most other applications employ optical scanners which can be used with normal type script but are more sensitive to dirt, paper quality *etc.* than magnetic readers.

To deal with characters independent of type fount and hand printed characters, requires a more general approach. In most applications the characters are first of all converted to a matrix representation using an optical scanner. The main difficulties to be overcome are:—

a. Displacement of characters in the matrix
b. Skewness of characters
c. Changes in size, aspect ratio and style
d. Noise-like effects such as ink blots, smudges, gaps or thickenings.

Some of these difficulties can be reduced by normalising each character with a shifting and scale changing operation before matching against prototype characters but changes in style and noise are still a problem.

One obvious approach is to look for character features which are independent of such variations, rather than to match the detailed structure. An early application of this type is described by Doyle[11]. The input character is converted to a 32×32 binary matrix and some of the noise effects reduced by filling in gaps and eliminating patches. Recognition is based on the probability of occurrence of 28 features such as the relative lengths of different edges, the maximum number of intersections of the pattern with horizontal and vertical lines and various concavities. Intersections, for example, are recognised as sequences of 1's separated by sequences of O's. The probabilities of each feature for each character are determined from known samples. A new letter is recognised by looking up the probability of each measured feature for each possible letter, calculating the total probability and identifying the input as the letter class with highest probability. This is an application of the maximum likelihood rule with the assumption of equal costs and prior probabilities. Doyle reported an overall error rate of 12% for 450 samples of the ten hand printed letters A E I L M N O R S T. The relatively high error rate may be partly due to the assumption of statistical independence of the various features necessary for a computation of the conditional probabilities.

A rather similar method to Doyle's has been reported by Grimsdale *et al.*[12]. A character is again converted to a 2-dimensional array of points by flying spot scanner and the data transfered to a computer. A programmed scan is used to search the array for the character and when found, the scan changes to follow it. A description of various segments of the character is built up in this way and assembled into a statement of its basic features. Recognition is by comparison with statements for stored patterns and a score is accumulated depending upon agreement between the details of the features. The unknown pattern is classified as the character with highest score. The exact basis of the scoring system and the error rates achieved are not, however, given in Grimsdale's paper.

Another approach to the problem of finding invariant features is to form the autocorrelation function of the input character—in effect by comparing the character with a displaced version of itself and counting the number of common matrix cells as a function of displacement. The result is more or less independent of translation, rotation and scale changes of characters within the matrix. The character description in the new measurement space obtained by sampling the autocorrelation function may then be cross correlated with the prototype patterns. A system along these lines has been designed at NPL for research into the recognition of hand printed numerals. The design has been proved by computer simulation and has also been implemented using special purpose analogue equipment.

Optical techniques are frequently used in work on pattern recognition and one of the most interesting possibilities is a recent proposal by Gabor[13] concerning the use of laser holography for character recognition. The use of holography for fingerprint identification is also being studied.

Holography is a technique for photographically recording both the amplitude and phase information in the wavefront scattered from an object. The photographic record or hologram is obtained by using a laser source to illuminate a photographic plate with coherent light scattered from the object and also with a background of coherent light. Interference between the background light and the wavefront from the object allows the phase information to be recorded and when the hologram is developed and illuminated by the coherent background alone, the original wavefront scattered by the object is completely reconstructed.

Gabor's proposal is to produce a hologram by illuminating a photographic plate with coherent light scattered from a printed or handwritten character and a coherent background from a combination of point sources coded to identify the character. When a character similar to that used in producing the hologram is presented to it, the identifying code word appears and can be detected by photoelectric cells. The important point is that a large number of characters and variants—Gabor suggests 30 variants of each alphanumeric character—can be stored on a single hologram by repeated exposures to the prototype characters. Independence of small translational variations can be obtained by placing the hologram in the rear focal plane of a lens viewing the character, giving a Fourier transform representation of the character. Essentially, then, the method deals with character variations by storing a large number of prototype versions and holography provides a very convenient way of doing this and of matching an unknown character against them. How well this method works out in practice has yet to be reported.

Highleyman has applied the hyperplane technique to the recognition of hand printed numerals. Fifty people each printed the numbers 0 to 9 within squares on a sheet of paper and an optical scanner was used to convert the numbers to a 12×12 binary matrix form. Each quantized number was then positioned in its matrix by aligning the centre of gravity with the centre of the matrix. The 45 hyperplanes forming the complete linear decision functions were computed using the iterative technique described in his paper. Results for the 500 design samples were 1% misclassification and 0·2% rejection but tests with an independent sample of 12 sets of numbers gave only 62% correct recognition. Highleyman attributed this to an unsatisfactory choice of measurement space—the original 144 dimensional space which was very dependent on pattern variations—and poor estimates of the hyperplanes due to too few design samples. The result certainly emphasises the importance of using independent test samples for a realistic assessment of a design.

Many other methods and results have been reported in the literature but it is difficult to draw any firm conclusions about the present position because of the variety of characters and sample sizes used by different workers. The general impression, however, is that error rates of less than 5% for poorly printed characters are difficult to achieve with present techniques.

A limitation of many methods is the use of a binary matrix representation. The eye can certainly resolve more than two intensity levels and it may be important to encode characters into several levels of transmitted or reflected intensity. A limited amount of context checking might also prove useful since even human readers have an error rate of about 3% for poorly printed letters seen out of context.

Speech Recognition

The position in automatic speech recognition is less advanced than in printed character recognition and there are no commercially available machines. The most general problem is the recognition of large vocabularies independent of the speaker leading to the possibility of a phonetic typewriter, for example. The great reliance placed by humans on the structure and statistics of the language as well as the individual words, makes this a very difficult problem. Most of the current work is limited to the recognition of small vocabularies of carefully spoken words such as the 10 decimal digits, where context is unimportant. Such limited vocubularies may nevertheless be adequate for the important application of direct communication with computers. Another aspect of speech recognition, of possible application in forensic science, is " voiceprint " identification—the recognition of the speaker rather than the words.

The input space used in speech recognition is nearly always some form of frequency analysis of the speech waveform. The acoustic energy of normal speech is concentrated in three or four frequency bands with relative positions in the spectrum which vary with time during the utterance of a word, giving a pattern characteristic of the word and to a lesser extent, of the speaker.

Some interesting experiments based on this sort of analysis have recently been reported by Tunis and King[14]. A spectrum analyser was used to detect energy peaks and its output was sampled every 30 ms. Interest was in the frequency locations of the energy peaks rather than their absolute energies and each word was represented by a 16×20 binary matrix in which rows corresponded to the 16 frequency bands and columns to succes-

sive samplings. Two male speakers and one female speaker were used and two vocabularies, each of 15 words which were also combined to give a third vocabulary of 30 words. Samples of from 35 to 50 sets of each vocabulary for each speaker were used in the design stage and separate samples of from 75 to 115 sets were used to test the designs.

An adaptive training technique was used to compute linear decision functions appropriate to each experiment. Fifteen hyperplanes were computed to separate each word from all the others in a 15 word vocabulary. The adaptive technique starts with a random sequence of words from the samples of a vocabulary and a tentative choice of hyperplanes. The first word in the sequence is then classified. If the classification is correct no changes are made but if wrong, the boundaries responsible for the error are corrected. This routine is carried out for each word in the sequence and the whole process is repeated until no further corrections are needed. If convergence is not achieved within a reasonable time, a new initial choice of hyperplanes may be necessary. Results with the first vocabulary (the numbers 0 to 9 and the words minus, plus, times, over, total) using the 320 dimensional binary space gave errors of 0·2% and 0·8% for the two male speakers and 2·4% for the female speaker—the location of the lower energy peak was found to be more erratic for female voices. No significant differences were found between results with different vocabularies for the same speaker but the recognition of words by one subject when using the decision function designed for the other speaker and *vice versa*, was poor. A number of transformations of the input measurement space were also tried but none of these gave quite such good results as the complete measurement space—presumably because it contained all the information available and the decision rule used this information efficiently.

The general conclusion from the work was that the simple measurement space described leads to a recognition rate of at least 98% for male speakers and vocabularies of up to 30 words. Recognition for speakers who had not contributed to the design sample was not satisfactory however and in this sense the chosen measurement space was not sufficiently invariant.

Results using Adaline[8] to recognise the spoken numerals one to 10 also give 98% accuracy for the recognition of words spoken by the individual used during training and 90% accuracy when tested with a new speaker—rather better than Tunis and King's result, possibly because four energy levels and some time normalisation were used in the Adaline experiments.

Conclusion

Automatic pattern recognition is a relatively new subject comprising an interesting mixture of statistical theory and computer technology. It has a wide range of potentially useful applications, from character and speech recognition to the identification of elementary particle tracks in bubble chamber photographs. The design problems are often formidable, however, and much of the current work is still at research level. Even the apparently simple task of automatically recognising hand printed numbers has yet to be solved satisfactorily.

The statistical basis of the design problems is the factor common to all pattern recognition work and had been particularly emphasised in this review. Statistical decision theory provides an optimum approach to many pattern recognition problems but the solutions are not always tractable and sub-optimum methods are often resorted to in practice.

The present position in automatic pattern recognition work seems to involve a division between the experimentalist, who is mainly concerned with the search for good pattern measurements and the theoretician, who tends to assume the existence of a statistically sufficient measurement space and considers only the analysis of the decision stage. Unifying these two aspects of the subject is undoubtedly one of the outstanding problems.

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A COMPENSATED CONDUCTIVITY WAVE-HEIGHT PROBE

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Admiralty Experiment Works

Introduction

Of the many methods for measuring instantaneous wave-height, one of the most attractive is that depending on the conductance of that part of a pair of parallel metal rods immersed in the water. The better qualities of the device include an inherent tendency to give a reading appropriate to the level of the surface of the main body of water and to ignore, unlike capacitance probes, drainage films and pluming due to motion of the water.

Requirements

There are two possible approaches to the measurement of conductance of the immersed probe which can give a linear law. One is to fix the applied voltage and measure the current variation the other to fix the current and measure the voltage. Constant voltage operation is the best choice, as the current density at the electrode surface is then constant and independent of immersion. AC must, of course, be used, to prevent polarisation effects, but this is only effective if the frequency and current density are such that the electrolytic gas film built up in one half-cycle is sufficiently incomplete to have a negligible effect on the overall conductance. To ensure this is far easier if constant voltage working is used.

The requirements for a stable linear probe may be stated as:—

(a) The exciting voltage across the probes is AC with frequency and current density such that polarisation effects are negligible.

(b) The electrodes are of corrosion resisting material and of constant size and shape throughout their length.

(c) The exciting voltage is not affected by changes in probe current.

The Practical Instrument

The first requirement in (a) above is more than adequately met by the use of a relatively high frequency (5000 Hz) and a voltage between probes of only 18 mV RMS.

The second requirement, (b), is met by precise construction of the probe, using stainless steel (18·8) as the electrode material. A range of probes has been constructed, with electrodes varying from $\frac{5}{16}$ in. diameter rods spaced two inches apart and three feet long to $\frac{1}{16}$ in. diameter spaced half-inch and 15 in. long. Flat electrodes cemented into fibreglass hulls and into fibreglass foil sections have also been used. One example of a rod probe is shown in Fig. 1.

The third requirement, (c), is met by the use of both negative (voltage) and positive (current) feed-back over the AF amplifier providing the excitation for the probe. These are adjusted to give precisely zero impedance at the probe. The general circuit arrangement is shown in the block diagram of Fig. 2 and it will be seen that the voltage feedback loop encloses the current measuring components.

The current through the conductance of the probe is measured by the current transformer T1 and its associated resistive shunt. The voltage across this is amplified by amplifiers A3 and A4 and demodulated and so provides the input for the recorder.

Compensation for changes in water conductivity with content and temperature is provided by correcting the AC voltage applied to the probe. This is done by feeding with a sensibly constant current, via transformer T3, an auxiliary probe (called the compensating probe, see Figs. 1 and 2) completely immersed in the same water as the measuring probe. The voltage developed across this auxiliary

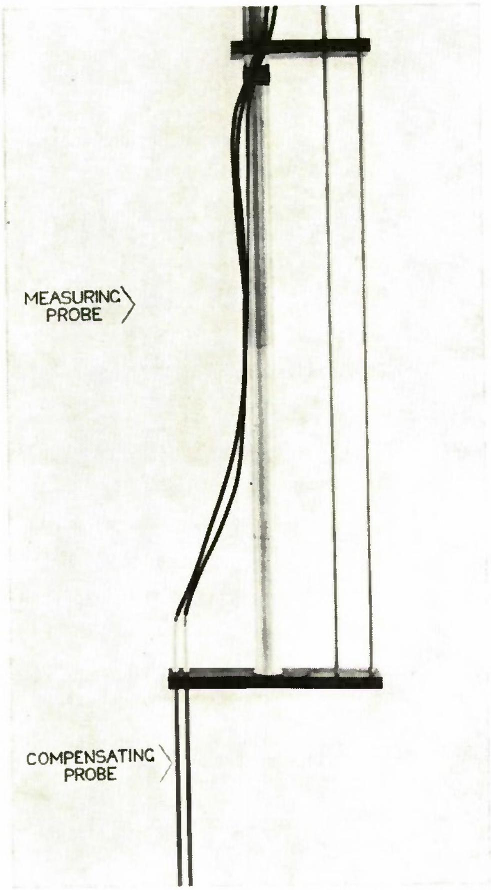

FIG. 1. A.E.W. Standard wave probe.

probe is then inversely proportional to water conductivity. The amplifier A2, exciting the main probe is fed from this, so providing complete compensation.

The feeds to both probes are balanced with respect to water potential by T3 and T1 and the symmetry is continued in the feed transformer T2. This is essential to prevent instability due to feedback between measuring and auxiliary compensating probes. The transformers are trifilar wound to ensure accurate balance.

There is a resistive "swamping" load across the measuring probe. If this is not included, the shunt inductive component of T2 become predominant at small probe immersions causing instability in the loops containing the amplifier A2.

The standing input to A4 is composed of components due to this swamping load (and transformer losses) and to the immersion of the measuring probe in the "zero" position—usually halfway in. The component due to the swamping load, *etc.*, is backed off by an adjustable antiphase voltage derived from the output of the auxiliary compensating probe as shown in Fig. 2. This voltage is fed into the mixer between A3 and A4 together with another adjustable antiphase voltage derived from the stable oscillator feeding the whole instrument. This voltage is used to back off the signal component due to the "zero" position immersion of the measuring probe.

Each amplifier, A1, A2, A3 and A4 has a large degree of negative feed-back to stabilise its gain. Very small residual changes of gain with ambient temperature do, however, still exist, resulting in

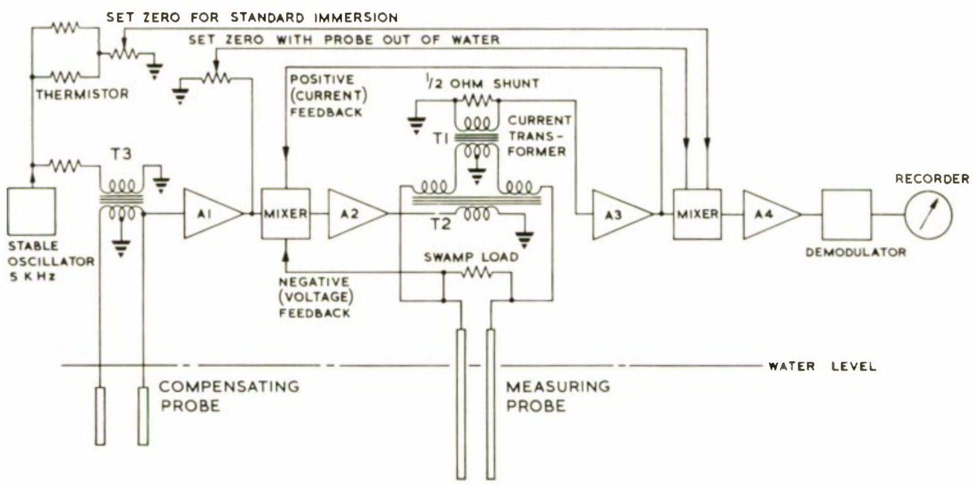

FIG. 2. Circuit diagram.

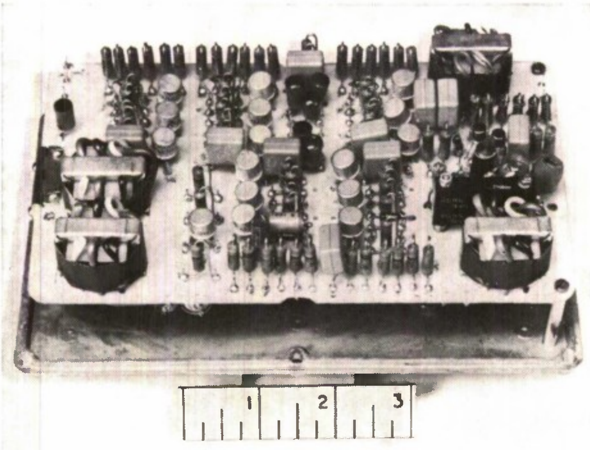

FIG. 3. General view of the instrument.

small zero drifts. Sensitivity drift due to this cause is negligible. The zero drifts are reduced to negligible proportions by supplying the backing-off voltage for "zero" immersion from a thermistor network as shown.

A general view of the instrument is shown in the photograph of Fig. 3. The basic design was completed while integrated circuits were still very expensive and conventional techniques were used. It would now be possible to use integrated circuit techniques with a considerable saving in size and weight. The present instrument measures $7\frac{1}{2}$ in. $\times$ $4\frac{5}{8}$ in. $\times$ $2\frac{1}{4}$ in. and weighs $3\frac{1}{4}$ pounds without the stable oscillator, which can be common to a number of probe units.

Stability and accuracy of the unit described are within $\pm 1\%$.

Recording

The output of the present instrument is ± 2 volts full scale with a current capability of 1mA. The current can readily be increased if required. The device is therefore capable of driving a pen or ultra-violet light recorder as well as a conventional meter, and the reasonably high output voltage fits it to feed most FM or digital recorders either directly or *via* a telemetry system.

Dynamic Calibration

The high accuracy obtainable with the instrument made the choice of dynamic calibration methods somewhat difficult. Two methods have been used.

In the first method, for initial evaluation purposes in the laboratory, the probe was attached to a scotch-crank assembly to give a vertical motion in a static water-tank. The output of the instrument was compared with that from a precision potentiometer operated by drum and wire from the same vertical motion. The stated accuracy was maintained to 2 Hz.

Calibration under working conditions in a large tank was done by lightly engraving a scale on the probe rods and using ciné photography to record the crest to trough height of the wave. This was compared with the reading obtained from the instrument. In this case the wave generation limit was 1 Hz and the stated accuracy was maintained. It was first established that the engraving used had no measurable effect on the static calibration.

Acknowledgements

Thanks are due to Mr. C. Wager and to Mr. M. Moody who carried out much of the constructional work.

Notes and News

Department of Naval Physical Research

By kind permission of the Admiral President, Royal Naval College, Greenwich, a C.V.D. Dinner is once again to be held in the Painted Hall. It will take place on 12th April, 1967 and attendance is to be restricted to males only.

Full details may be obtained from Mr. R. H. Williams, D.N.P.R. (C.V.D.), Old Admiralty Building, Whitehall, telephone WHItehall, 9000, ext. 631.

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Naval Scientific and Technical Information Centre

Mr. J. C. Dunne has recently joined the Centre as Head of the Reports Section. He previously served with the Technical Information and Library Section of the Ministry of Aviation.

The N.S.T.I.C. quarterly publication "Translations Available and in Preparation" is now being distributed in its new format to all Research establishments and other interested authorities. Requests for additional copies should be made to the Librarian, N.S.T.I.C.

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Admiralty Compass Observatory

The Admiralty Compass Observatory was invited by the United States Office of Navy Research to be represented at the meetings of its Gas Bearing Co-ordinating Committee on a permanent basis. This Committee, which meets at regular intervals to exchange information on gas bearing work currently in progress, comprises representatives of U.S. Government departments, firms engaged on Government-sponsored work, technical organisations and universities.

At the April 1966 meeting held at Columbia University, A.C.O. was represented by Mr. H. J. Elwertowski, Chief Scientist and Deputy Director (R. and D.) and Mr. A. G. Patterson. Mr. Elwertowski gave an account of the organisation of the British Ministry of Defence with particular reference to its interests in and work on gas bearings. Mr. Patterson reviewed some of the work currently being undertaken on the boundary lubrication of bearing surfaces.

Subsequently Mr. Elwertowski and Mr. Patterson visited some of the organisations represented on the O.N.R. Committee, including Nortronics, Norwood, Massachusetts; the M.I.T. Cambridge, Massachusetts and Autonetics, Anaheim, California, to discuss common problems in connection with gyro gas bearings.

Mr. H. B. Hewitson visited Paris during March to advise the United Kingdom delegate to the Organisation for Economic Co-operation and Development on matters connected with Gyro Compass Equipment.

Mr. E. Hoy visited the Perkin Elmer Corporation, Norwalk, Connecticut, U.S.A., and Sperry Polaris, Long Island, New York, during August for discussions on items of optical test equipment unique to the U.K. Polaris programme.

Mr. Elwertowski, Dr. J. Preston and Mr. Patterson visited the United States during December, primarily to attend an International Symposium on Hydrodynamic Gyro Bearings at the Massachusetts Institute of Technology. Mr. Patterson presented a paper entitled "Boundary Lubrication Problems in British Marine Gas-Lubricated Gyros."

During this period in the U.S.A., Mr. Elwertowski and Dr. Preston visited Nortronics, Norwood, Massachusetts, and the U.S. Naval Applied Science Laboratory, New York, for discussions on the new Ultra Precision Gyro Test Equipment being acquired by A.C.O. Mr. Elwertowski and Mr. Patterson visited the U.S. Naval Research Laboratory, Washington D.C., to discuss boundary lubrication problems of common interest. Finally, Mr. Elwertowski together with two representatives of S.E.R.L. visited Honeywell, Minneapolis and Sperry, New York, for talks on laser gyros.

Mr. D. Bromley has joined A.C.O. from A.M.L.

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Admiralty Experimental Diving Unit

The A.E.D.U. has undergone some traumatic experiences in the last few years. After 15 years of "Stable Government" under various Superintendents of Diving, each staying about five years at a stretch, and with one continuous leader of the R.N.S.S. Team, Tom Grosvenor died suddenly in 1964 only months after his post had been upgraded to C.E.O. The Unit then acquired Ray Common from the A.U.W.E. as leader, and almost immediately the post of the Superintendent of Diving became a career post for R.N. officers of the Diving specialisation. In consequence, the next link of continuity broke in 1966 when Commander E. C. Hannen was posted to Plymouth Command, and relieved by Commander Philip White, M.B.E., R.N., a qualified and vastly experienced Clearance Diver, holding as trophies of the past, command of the R.N. divers who had to cope with the Post Suez mess. Almost simultaneously the Deputy Superintendent of Diving, Lt. Cdr. Morty Drummond, well known, equally experienced Clearance Diver, was transferred in exchange for Lt. Cdr. "Jackie" Warner, almost the last of the "Old Guard" post-war Clearance Divers! The avalanche of change continued when Miss M. Barnett, Clerical Officer and mainstay of service and civilian alike for 12 years, was obliged to transfer to Portsmouth Dockyard for experience to qualify for promotion.

During these changes, the Unit was fully engaged in Deep Diving Research, and the usual full programme of development of new and improved diving equipment, opening and equipping the new Deep Trials Unit at the R.N.P.L., Alverstoke, under ex-Deputy S. of D., Lt. Cdr. Bill Filer, R.N. Retd., RO.II. Trials at sea with H.M.S. *Reclaim* put R.N. Divers temporarily ahead of the world in 1965 with a 600 ft. working dive, attracting much publicity for the Unit and the Service. Mr. Williams went to Sealab II, and Mr. Common went to Conshelf III. B.B.C. and I.T.V. featured the work of the Unit in various programmes, and we received almost embarrassing coverage in the National Press.

A proposal for a new, permanent building for the Unit has been approved, and tenders are being considered. This building should be completed before the

end of the year, if there are no setbacks. The accommodation is more than urgently required. At present the Unit staff breathe by numbers, especially in the Drawing Office, where six people and equipment work in a total floor area of 300 sq. ft. and " accommodation standards " are regarded as naughty words.

During the year, visitors have included: Sir Michael Carey, Secretary of the Navy Department; The Commander-in-Chief, Portsmouth, Admiral Sir F. H. E. Hopkins; The Director General Weapons (Naval), Rear Admiral A. M. Lewis; The Director of Weapons Research Development (Underwater), Dr. R. Benjamin; Captain C. R. Sims, R.N., lately Captain of the A.U.W.E.; Captain G. Bond, U.S.N., of Sealab Project; Dr. H. J. Taylor, Superintendent of the Royal Naval Physiological Laboratory, and many others.

Commander White and Syrl Williams, Senior Experimental Officer, addressed the BS-AC International Conference for Underwater Activities in Brighton in September 1966, in company with Commandant J. Cousteau, and Captain G. Bond, U.S.N., and others. Previous to this public appearance, Commander White had attended and advised on the successful salvage of a Russian YAK aircraft from a lake in the British Sector of West Berlin. The whole Unit, and in particular Messrs. Williams and Noad, was involved in the salvage of the first Buccaneer Mk. II to crash, in 342 ft. of water off the Lizard Point. H.M.S. *Reclaim*, " Our " diving ship, played a key rôle in this operation. Mr. Williams was promoted to Senior Experimental Officer on 1st January, 1967.

Mr. Philip Payne, Experimental Officer, with 15 years in the A.E.D.U. has attended on various firms involved with production of diving equipment during the year, and conducted an investigation into an explosion in a power-operated oxygen Booster Pump at the Diving School in Plymouth.

Mr. Michael Kettle has continued to progress his development work to extend the use of divers in underwater ship maintenance, with propeller changes, bottom cleaning and underwater painting, and the development of a whole range of pneumatic power tools converted from surface to effective underwater use. These include impact wrenches, chippers, scrubbers and saws. He has visited Marseilles to see a commercial hull cleaning project, now making an impact on merchant shipping.

The Unit continues to maintain liaison with, and to advise many organisations including the R.N.P.L., R.N. Medical School, the R.N. Hospital, Haslar, the School of Aviation Medicine, the C.D.E.E., Porton, the N.B.C.D. School, Hilsea, Portsmouth, the A.U.W.E., Portland, and also the British Sub-Aqua Club, the National Underwater Instructors' Association, the Duke of Edinburgh Award Committee for Underwater Activities, the Co-Ord. Committee for Maritime Technology, the Surrey Constabulary and the Portsmouth Fire Service.

The programme for the future continues to be very full and promising of great interest to those involved.

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Admiralty Experiment Works

In November, Dr. Purcell (C.R.N.S.S.) and Mr. Burt (A.R.L.) visited A.E.W. for further discussion of the R.N.S.S. rôle. Later in the month Senior Officers of the French Ministry of Defence visited A.E.W. at the conclusion of their London discussions with Mr. Lythall (C.S.R.N.). These were Ingenieur General du Genie Maritime Castelan (Head of Service Technique des Construction et Armes Navale), IGGM Meunier (Head of Equipment Group of STCAN), Ingenieur en Chef du Genie Maritime Baron (Head of Bureau for New Construction and Foreign Relations, Direction Techniques des Construction Navale), IGGM Lago (French Naval Attache in London).

In December, Sir Alfred Sims (D.G. Ships) accompanied by Mr. Telfer (Civil Assistant) toured the Establishment and addressed the Staff on the future problems and prospects of the Ship Department. Sir Alfred emphasised the importance of designing ships to a price which would allow them to be produced in quantity. In December also, A.E.W. were hosts to the British Towing Tank Panel consisting of Messrs. Crago and Flewitt (British Hovercraft Corporation), Glen (J. Brown Limited), Lackenby (B.S.R.A.), Lister and Moore (Vickers Limited), and Silverleaf (N.P.L.).

In November, Mr. Booth visited the U.S.A. to attend the " Ships Systems Control Symposium " held at the Marine Engineering Laboratory, Annapolis, and also visited the Applied Physics Laboratory of the Johns Hopkins University, the David Taylor Model Basin, Hydronautics Incorporated and Cape Kennedy. Mr. Wall visited the Basin des Carennes, Paris, for discussions on propeller design.

Mr. Lloyd (S.O.) has recently joined the establishment for work on submarine stability and control.

A fortnight Summer School on the hydrodynamic aspects of " Directional Stability and Control of Ships " is being sponsored jointly by University College, London, A.E.W. and N.P.L. and will be held at N.P.L. (first week) and A.E.W. (second week) from 26th September to 6th October 1967. The School is open to graduates or equivalent and will consist of lectures, demonstrations and tutorials. Those interested in attending are invited to write to Mr. Goodrich, National Physics Laboratory (Ship Division), Fagg's Lane, Feltham, Middlesex, for further details and information on fees, accommodation, etc.

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Admiralty Materials Laboratory

Dr. R. G. H. Watson, S.P.S.O., left A.M.L. to take up his new appointment as Head of R.D.F.(N) at the beginning of January, 1967. He had been Head of the Chemical Engineering Division since 1956. All staff at A.M.L. will wish him every success in his new appointment.

Mr. D. A. Fanner, P.S.O., has been released from the Army Department and joined A.M.L. on 3rd October 1965, to take charge of the Fuel Cell Research Team.

Dr. T. C. J. Ovenston visited various industrial and Service materials centres in the U.S. during October 1966, in his capacity as Navy Department representative on Sub-Group P, T.T.C.P.

Mr. D. Birchon visited a number of U.S. establishments and laboratories during October 1966, both as a member of the M.O.D./M.O.A. team led by Professor H. Bondi, and also to discuss metallurgical problems of special interest, including high strength steels and high damping capacity alloys.

Dr. R. G. H. Watson and Mr. D. A. Fanner, in company with Dr. E. C. Wadlow of D.M.R.(N) visited Sweden in November 1966, to discuss the progress of the Swedish Navy's fuel cell power unit for submarine propulsion which has now reached an advanced stage of development.

Mr. J. McFadyen, Mr. A. A. Law, and Dr. D. K. Ross, all members of the A.M.L. Fuel Cell Team, visited several U.S. research and development laboratories during the autumn to discuss the chemical, material, and engineering aspects of fuel cell research. Mr. McFadyen also attended the October fuel cell meeting of the Electrochemical Society in Philadelphia.

Mr. N. I. Hendey attended, as the British delegate, the 5th Plenary Session on Biological Deterioration of Materials sponsored by the O.E.C.D. Directorate for Scientific Affairs held in Paris at the end of October, 1966. He also attended the 15th Research Conference on the Prevention of Microbiological Deterioration at the U.S. Army Laboratories, Natick, Mass., U.S.A., in November 1966.

Mr. K. R. Tuson visited Toulon and Singapore during October 1966, in connection with work on the propulsion of underwater swimmers.

Mr. L. J. Pearce was given leave to enter the University of Newcastle in October 1966, in order to undertake a year's M.Sc. course in Electrochemistry.

Miss P. M. Steward has been awarded a Treasury Bursary and has started a degree course in Chemistry at the University of Southampton.

Dr. C. A. Parker presented a paper entitled "Fluorescence and Phosphorescence Analysis" at the symposium on "Newer Physical Methods of Biochemical Analysis" held jointly by the Association of Clinical Biochemists and the Association of Clinical Pathologists at Imperial College, London, on 1st October, 1966.

Mr. D. Birchon presented a paper on "Silicon Nitride—a Ceramic for Engineering Purposes" at the Annual Meeting of the British Association for the Advancement of Science at Nottingham on 6th September 1966. His presentation was included in a B.B.C. television coverage the same day. Mr. Birchon also gave a talk on "Silent Metals" on the B.B.C. Home Service on 5th November, and a brief interview on the same topic was broadcast on 29th December.

The following papers by members of the Staff have been published:—

"Mechanism of Delayed Excimer Fluorescence in Solution" by C. A. Parker, in *Spectrochim. Acta*, **22**, (1966) 1677.

"Photo-reaction of Benz(a)Pyrene in Solutions Containing Polymer", by C. A. Parker and C. G. Hatchard, in Photochem. *Photobiology*, **5**, (1966) 699.

"Determination of Triplet Formation Efficiencies by the Measurement of Sensitised Delayed Fluorescence", by C. A. Parker and Thelma A. Joyce, *Trans. Faraday Soc.*, **62**, (1966) 2785.

Naval Construction Research Establishment

As part of a U.S./U.K. personnel exchange programme Dr. C. S. Smith is now serving a year in the Surface Ship Structural Division at D.T.M.B., Washington. In exchange Mr. K. Hom from D.T.M.B., has just completed a four month period at N.C.R.E. working on structural analysis whilst Mr. R. Raetz also of D.T.M.B. is serving a year at N.C.R.E. on similar work.

The premier honour of the Inst. of Welding, the Sir William J. Larke Medal which is given annually for the best welding research paper of the year, has been awarded to Dr. A. P. Bennett and Mr. P. J. Stanley for a paper "Fluxes for the submerged-arc welding of Q.T.35 steel," published in the British Welding Journal of February 1966. The work was carried out in the Welding Development Laboratory at N.C.R.E., although Mr. Stanley is now serving at A.M.L. An account by Dr. Bennett of the work done at N.C.R.E. up to and since the publication of the paper is to be included in our Journal.

Services Electronics Research Laboratory

A symposium on Fast-Neutron Radiotherapy was held on the 30th November 1966. Amongst the 50 visitors to S.E.R.L. for this event were physicists, radiobiologists and radiotherapists, both from British hospitals and overseas. See this issue, page 56.

Mr. A. F. H. Thomson and Mr. P. G. R. King (in conjunction with A.C.O.) visited the U.S.A. in December to investigate American progress on ring laser inertial rotation sensors.

Dr. F. A. Cunnell left S.E.R.L. on the 3rd January to take up an appointment at R.R.E. to superintend the Applied Physics and Technical Services Division.

Mr. P. Gurnell paid a visit to Paris in January in connection with the Anglo-French Working Group on Valves and Semiconductors. The purpose of the visit was to review the exchange of information of the Working Party on Semiconductors. During the visit he discussed with C.S.F., Paris and La Radio Technique, Caen, progress on semiconductor materials.

Dr. D. J. Oliver of D.N.P.R./C.V.D. and Mr. R. J. Sherwell of S.E.R.L., paid a visit to France in December to discuss silicon integrated circuits.

OBITUARY

FRANCIS B. SHAW, O.B.E.

Francis Shaw, whom older readers will remember as Chief Technical Adviser to the Superintendent of the Mine Design Department, in H.M.S. *Vernon*, died of leukemia on 14th November last. He served with M.D.D. throughout most of the 'Thirties' but had already established his reputation as an engineer before joining the Admiralty. For some time previously he had worked in Siam where, for his services he was awarded the Order of the White Elephant.

By the middle of the 'Thirties', items like buoyant Contact mines, harbour defence mining and depth charges had reached a high state of development, but new ideas such as mines laid by aircraft and magnetic mine firing systems were under active development. Mr. Shaw was therefore very actively concerned with these items and with the expansion of activity which occurred just previous and subsequent to the outbreak of war in 1939. He had the 'diplomatic' characteristics required for his post as Chief Technical Adviser and as he preferred to deal with matters in a broad manner was fortunate in having a very able staff to handle details. Amongst many worthy of mention, Mr. F. Pickford, who also died recently, who dealt with all aspects of buoyant mines; Mr. C. B. Johnson, who was responsible for the ideas of magnetic mine firing units and Mr. H. J. Taylor, who invented the depth charge and was responsible for the ideas and detailed design of many components which proved of inestimable value during the 1939-45 war. These men were all of strong character and Mr. Shaw probably had need of all his 'diplomatic' abilities in dealing with the various situations which arose in what was at that time a somewhat isolated community.

Early in the war Mr. Shaw was sent to Washington as a member of the British Admiralty Delegation, to advise on mine warfare and equipment, where he remained until his retirement in March 1948.

He continued to live in Washington and became consultant in mining matters to the U.S. Naval Ordnance Laboratory.

Of these years Dr. Ralph D. Bennett, now with the Martin Company, writes:

"My acquaintance with Francis Shaw began soon after his arrival in Washington, D.C., as a member of the British Admiralty Delegation early in World War II. We, at the Naval Ordnance Laboratory, were already a group of considerable size, bringing to the problems of sea mine development a great deal of science and engineering but, for most of us, little or no experience with the sea. We were learning the hard way, and far too slowly, the extreme rigors of the ocean environment.

Mining had not had strong support in the U.S. Navy between wars so that the numbers of officers and scientists with any practical mining experience at all were very small. The arrival of Francis Shaw, with his long experience and broad knowledge of mining and the ocean environment, brought us a valuable, practical supplement to our development technology. His pleasant and attractive personality made his acceptance quick and easy, and we were eager for his advice and help.

Francis was, of course, in an excellent position to draw on members of the very active and ingenious British mining organization for current experience. He fostered a flow of information which saved us from many mistakes, and did much to keep us from developing procedures or devices which were obsolete or useless. I have always felt that the exchanges which he helped to promote were an important factor in the ultimate great success of the U.S. mining effort in World War II.

It was my pleasure to visit the United Kingdom mining establishments on several occasions with Francis as a guide. His knowledge of these installations and their people made these visits efficient, productive and useful. In addition, it was a pleasure to travel with him and to see the United Kingdom and meet many of its people in a way not usually open to the unofficial visitor.

His many friends at the Naval Ordnance Laboratory and elsewhere in the United States Navy learned with deep regret of the loss of this long time friend."

Mr. Shaw is survived by his wife, a son and two daughters, to whom, on behalf of his many U.K. colleagues we, also, offer our sincere condolences.

RETIREMENT

F. M. G. HUTTON

Mr. Hutton, who retired on 28th February 1967, was born in Devon and received his early education at Wellington College. From there he went to Emmanual College Cambridge where in 1930 he took his B.A. degree in Mechanical Sciences. He became an A.M.I.E.E. in 1936.

From 1930 to 1934 Mr. Hutton was Assistant to the Supply Engineer of the County of London Electric Supply Company and for the next five years was Personal Assistant to the Engineer-in-Chief of the company. During this period his work embraced technical and financial planning, forecasting and analysis in connection with the engineering side of electricity supply and load and tariff economics.

In January 1940 Mr. Hutton joined the Service as a Temporary Experimental Officer at H.M. Signal School, Portsmouth, and afterwards served at A.S.E. Witley and A.S.W.E. Portsdown. During this time he was mainly engaged on the engineering design of radar equipment and his work was recognised by promotion to Principal Scientific Officer in 1948.

Mr. Hutton was transferred to Headquarters in 1960 joining D.R.D.S. Here he was primarily concerned with the preparation of research and development surveys and papers for the Defence Research Policy Committee. He was also involved in R.N.S.S. Staff Allocations and the R. & D. Vote Estimates.

In all his work Mr. Hutton was a perfectionist, and the standard which he set himself was not always relished by the many people with whom he had to deal. By his persistence and example however he did much to influence the attitude of people to their tasks with much benefit to the Service. He takes with him our best wishes for a long and fruitful retirement.

Books available for Review

Offers to review should be addressed to the Editor

Anatomy and Physiology for Radiographers.
Second Edition.
J. E. Blewett and A. M. Rackow.
Butterworth & Co. (Publishers) Ltd. 1966. 57s. 6d.
(No. 1481)

Vibration in Civil Engineering.
Editor B. O. Skipp.
Butterworth & Co. (Publishers) Ltd. 1966. 85s.
(No. 1482)

Basic Ideas in Neurophysiology.
T. D. M. Roberts.
Butterworth & Co. (Publishers) Ltd. 1966. 25s.
(No. 1483)

Introduction to Physics.
H. E. Gauss.
George Newnes Ltd. 1966. 10s. 6d. (No. 1484)

Introduction to Mathematics.
C. C. T. Baker.
George Newnes Ltd. 1966. 10s. 6d. (No. 1485)

Elective Physics for the Ordinary National Certificates and Diplomas in Sciences.
K. D. Barritt.
English Universities Press Ltd. 1966. 35s. (No. 1488)

Organic Chemistry. (Teach Yourself Books)
K. Rockett.
The English Universities Press Ltd. 1967. 10s. 6d.
(No. 1489)

Workshop Experiments for Mechanical Technicians.
D. A. Moore.
Blackie & Son Ltd. 1966. 15s. (No. 1490)

Deformation and Strength of Materials.
P. Feltham.
Butterworth & Co. (Publishers) Ltd. 1966. 25s. (No. 1492)

Fibre Reinforced Materials.
G. S. Holister and C. Thomas.
Elsevier Publishing Co. Ltd. 1966. 45s. (No. 1493)

Book Reviews

An Introduction to the Special Theory of Relativity. By R. Katz. Pp. 132. London. D. Van Nostrand Co. Ltd. 1964. Price 12s.

Since Einstein first persuaded the scientific world that many observations could not be explained by the application of " commonsense ", there have been many books which have attempted to introduce the reader to the principles of the Special Theory of Relativity. Here, in the Momentum Books Paperbooks series, is another which although perhaps lacking the lucid simplicity of the popular elementary introduction by Einstein himself, or the elegant traditional scholasticism of Max Born's work, is, in its own mid-twentieth century way, a worthwhile book which draws upon modern examples, such as particle physics, for instances of the fields in which relativistic phenomena are encountered.

As is usual with books of this nature, the author starts by considering classical dynamics, thence extending his treatment, by introducing the Lorentz transformation, to the examination of bodies travelling at speeds comparable to that of light. Further implications of this transformation upon Force, Motion, Energy and Momentum are next investigated. This leads on to a more general survey, under the heading of Some Relativistic Phenomena, which covers subjects such as pair production and annihilation, Compton Scattering, π_0 Meson production and gravitational red shift. The last chapter deals with Electromagnetism, underlining the basic accord between electrodynamic theory and Special Relativity. Problems, with results, are included at relevant places throughout the text.

Since the book is intended as an introduction to the subject, chapter and general bibliographies are included as a guide to further reading. There is little in the text to which the more informed reader can take exception, unless he be, as yet, unconvinced of the validity of the time contraction effect in biological clocks. The level of mathematics required for reading this book is not high, an elementary knowledge of calculus being sufficient, and it fulfils its object of providing an easily assimilated introductory text.

R. J. Male

A Basic Science Course for Secondary Schools. By M. Robinson, R. C. Champeney, R. N. Clark, R. Garwood, R. J. Kerrigan, R. W. West. Pp. viii + 222. London; Longmans, Green & Co. Ltd., 1966. Price 13s. 6d.

The six authors, currently teaching in and directing the science departments of large secondary schools, present in this book a framework for a common basic science course for the first three years of secondary education.

The three year course is based on three periods per week for the first two years, and rather more time for the third year a 10 week term is assumed, to allow for revision, outings, examinations etc.; one week is allowed for each topic and this results in 10 topics per year from each of the three scientific branches, Physics, Chemistry and Biology, a total of 90 topics in all.

Each topic has four sections, teachers' theoretical background, demonstration, pupils' notebook and class practical; each section is numbered and keyed to each other in developmental steps providing an order for conduct of the lesson.

One is tempted to feel that if such a complex system of leading science teachers by the nose is really necessary, then the natural outcome of the desperate shortage of teachers must indeed be a pretty desperate depth of quality. The authors' introduction however, evaluates the teacher shortage in terms of 14,000 science teachers responsible for three million children and, although it is not clear to the layman what these figures really represent, one interpretation, which your reviewer will not defend, suggests that solid classwork for a six hour day, 30 hour week, with classes of at least 20, by all the 14,000 teachers, would just complete the course, with no-one left to do the administration and other chores for which teachers are responsible. Even if this interpretation is wildly in error, the need, which the authors claim to be meeting, to help novice and even experienced science teachers, is evidently real.

The book is offered as an attempt to provide a systematic basis for the production of scientific intelligence, in the hope that keen colleagues will adapt and re-edit the material, and obviously with the captive reading public passing through the training colleges well in mind. The authors are well qualified to meet this need, they have organised their own lessons and departments in a variety of schools, are very conscious of the fact that many national bodies are currently working on curriculum design and that many schools and training colleges are currently re-examining their syllabuses in the light of the new Certificate of Secondary Education and the Curriculum and Examinations Council.

The authors belong to that devoted section of workers operating from a sense of pure vocation and, one fears, in a minority group, who are dedicated to the doctrine that teaching really can change the innate abilities of the pupils; they regard the rapid change in secondary education as a stimulus and a challenge and one can only hope that their influence will be wide and their attitude triumph over the jaundiced outlook of their reactionary adversaries; for nothing is more certain than the fusion of Grammar and Secondary Modern educational systems and an unwillingness to make the new systems work can only delay the inevitable at the pupils' expense.

The reviewer's qualifications for reviewing this book must be shared by many thousands, who are fathers of children in the age group with which this book is concerned, who are supporting these children by doing work of a more or less scientific nature and who are in continuous demand for explanations of explanations provided for these children by their teachers.

Good or bad, the book must be recommended, by virtue solely of its subject matter, to all adults who share the reviewer's natural curiosity about what is being taught to the generation on which we are all depending for the maintenance of our living standards in old age.

With such minimal qualifications it would be presumptuous to criticise this book even had many critical comments been evoked by its study; in fact few were: time should be found, one feels, for the topic of energy conservation, surely an integral part of a basic knowledge of general physics; and shouldn't electro-magnetic waves get a mention somewhere, the familiarity of 12 year olds with this phenomenon should surely ease the task of understanding ! Other omissions were noted with regret, but each time one thought of a pet topic which should

be included, one was faced with the task of removing some other topic from the syllabus in order to make room for it.

This reviewer was also a little dismayed by the marked similarity of the demonstrations to those presented to him some 35 years ago; Nobel physics prize winner, Dr. William Shockley has written, "the experiences that stay in our memory are those that are dramatic, or are exaggerated, or are unusual in some other way". It is difficult to imagine teachers obtaining much dramatic effect from many of the demonstrations in this book, especially with children who can carry radios in their shirt pockets, who accept automated aids in the home as a matter of course and who can watch spacemen being shot into orbit, as it happens, 5,000 miles away. It may be that these demonstrations are designed for a particularly parsimonious budget, and it must be admitted that your reviewer always achieved his most phenomenal successes many years ago simply by snapping school rulers over the edge of the desk with the aid of the air pressure on a sheet of foolscap paper, but surely some of our national income would be well spent in making science more exciting.

Another point which occurs to the reader is that if the first three years' work is so similar to that which we undertook 35 years ago, when do the young of to-day begin to catch up with the extraordinary developments of those 35 years ?

A real attempt to break down the boundaries between the science subjects is very welcome and many cross links and leads out of each topic are provided. Follow-up suggestions for each topic are also provided and altogether the book provides a sound, if somewhat dull, systematic basis upon which the keen teacher can exercise his ingenuity to provide the inspirational spark without which all teaching is simply examination fodder.

The net result of all the critical effort was really a humble realisation of the enormity of the task facing present day science teachers and a feeling that the interest and support given to this most vital of national investments is totally inadequate.

R. L. Short

Classical Dynamics of Particles and Systems. By J. B. Marion. Pp. xv + 576. Academic Press (London) Ltd. New York, London 1965. Price 92s.

At rather less than 2d. per page, this book is good value indeed, even if the price may deter some private buyers. The undergraduate (for whom it is written) who works conscientiously through it will acquire a really comprehensive knowledge of the subject. He will also have worked very hard. Thoroughness is the keynote and if the going is necessarily a little heavy here and there, it is relieved by many attractive features. Salient formulae are "boxed"; each chapter opens with a description and justification of its aims and contents; interesting historical notes abound; references are not only plentiful but are also described; diagrams are always adequate; the writing is clear and quite innocent of tiresome 'Americanisms', and there are many worked examples on all topics

The first two chapters equip us for much of what is to come with a detailed account of matrices and vector calculus. The approach to vector analysis through co-ordinate transformation is basic and will amply repay careful study. Chapter 3 presents familiar applications of Newton's laws of motion, after a useful consideration of the status of scientific laws. The value of the first law, however, is not entirely clear here since "it conveys only a precise meaning for *zero force*", whereas Eddington's claim that the law lacked content is described as unfair. Frames of reference and the problem of absolute rest bring in relativity, whilst the limitations of Newton's system in the microscopic realm are indicated by a brief account of the uncertainty principle. The author does well to remind us that the conservation 'laws' are indeed not laws at all but are simply derived from Newton's laws and are similarly limited. Special relativity follows naturally in Chapter 4 and a recent correction to relativistic observation is noted; a high-speed object appears as rotated, and not distorted in one dimension. Chapter 5 on potential theory presents familiar material whilst emphasising the virtues of scalars.

The motions of linear oscillators under free, forced and damped conditions are conventionally treated in Chapter 6 and provide examples by which the author introduced the concept of phase space. Impulsive forces are included with a section on Green's function. The non-linearity of real restoring forces is emphasised from the outset, however, and the following chapter deals at some length with non-linear oscillations and the solution of examples by successive approximation and perturbation methods. An example featuring non-linear impedance would have been useful.

The use of Hamilton's Principle for tackling complicated dynamical problems is a main theme of this book and Chapter 8 prepares the way with some elementary but adequate instruction in the calculus of variations. The assertion that Hamilton's Principle is more fundamental than Newton's equations is made entirely convincing in Chapter 9; the statement of the Principle is followed by a derivation of Lagrange's equations; the latter are shown to be equivalent to those of Newton, from which the Principle is then 'derived' and the earlier study of scalars, transformations and phase space is given point in the process. Elastic collisions and central-force motion, with applications to celestial and microscopic phenomena, occupy two chapters of familiar topics and useful sections on scattering cross-sections and a mercifully brief look at the three-body problem.

The practical importance of non-inertial reference frames, the subject of Chapter 12, is illustrated mainly by motion relative to the Earth. A rather provocative description of centrifugal force as fictitious prods us into a reminder that, with the Coriolis force, it is merely a device allowing us, as it were, to put Newton where he has no right to be—which is precisely what we do in insisting that something must 'balance' centripetal force. In Chapter 13 rigid-body dynamics brings in a derivation and discussion of inertia tensors, symmetrical tops and the stability of rotating motion. Here again are vital links with the first three Chapters. Chapter 14 moves us on to systems with many degrees of freedom; a gentle lead in with two coupled oscillators and then serious business with η-degree systems, eigen-vectors and —frequencies, normal co-ordinates, and all explained with great clarity. Much of this chapter is devoted to the loaded string, the non-uniform case being discussed at some length for its mathematical interest in relation to quantum mechanics, a subject for which the whole book is a preparation. A rather modest treatment of Fourier analysis closes this chapter.

The next, and last, is on the wave equation. Whilst restriction to the one-dimension case is no doubt due to space considerations, the author nonetheless gives us the essentials with characteristic thoroughness. Separation of the equation, group and phase velocities, dispersion, the filtering properties of loaded strings and analogous electric networks, Fourier integrals and wave packets. Almost as an afterthought we finally return

to the problem of solving the equation with simple boundary conditions. The space given to seven appendices on fairly basic and easily accessible mathematical topics would surely have been better filled with, say, something on techniques for solving the wave equation with less simple conditions. We learn by doing, and the many and varied examples are yet another excellent feature of this volume which, incidentally, supplies answers and hints.

The end—marked by a most apt text from Ecclesiastes—is reached with a sense of having done much more than learnt or re-learnt a good deal of applied mathematics. The mathematics is never displayed for its own sake but remains secondary and relevant to Nature's phenomena, and the simplicity and unity sometimes apparent behind Her complexities. And that alone raises this book above so many leaden volumes in the same field.

One or two quite trivial and obvious errors were spotted.

P. H. G. Crane

The Physics of Thin Films, Volumes 1 and 2. Edited by G. Hass and R. Thun. Pp. 350 and 441. Academic Press—New York and London. 1963 and 1964. Price 93s.

The two volumes are the first in what is intended to be a series of annual review volumes covering the whole field of thin film physics. The first volume contains six and the second volume seven articles each by different authors covering aspects of film production, basic physics, a wide range of physical properties, and methods of measurement. The authors are acknowledged authorities in their specialist fields and with one exception American, but the very numerous references (one article has just 200 references) include many to British and other non-American journals. There is some unevenness in both standard and style as would be expected with a number of different authors, and a little overlapping, also inevitable, is apparent. However, if general criticism is to be made it is perhaps that the field covered is far too wide and that each volume contains only two or three articles likely to be of interest to any single reader. The series is therefore more appropriate to the library shelf than to individual ownership. In future volumes perhaps the articles in any one volume could be selected to cover a narrower specialist field.

In a series of survey volumes the choice of topics at any time must presumably take account of any recent notable advances and also of fields of interest which may be particularly relevant to currently active fields of application. In the first volume of such a series an introductory broad "setting of the scene" might be expected To some extent this appears to have been the intention in this case in the first article, Ultra-high Vacuum Evaporators and Residual Gas Analysis, which is good though in parts a little cursory. The final section, dealing with the effects of different gases on film formation and properties is really out of place and is in any case far too short to treat the subject adequately. The next two articles deal respectively with theoretical aspects of the optical parameters of films and with the practical aspects of preparation and optical measurements of films for the ultra-violet. The fourth article on "The Structure of Thin Films" is undoubtedly the most important in this first volume and the topic should have been treated very fully. It is in fact one of the shortest and, further, half of it is devoted to a description of the various methods, optical, electron microscope, *etc.*, of studying film structure. The remaining 20 pages cover the whole subject of structure and inevitably many important aspects receive little more than literature references. The article on low temprature films is a clear, well balanced, textbook discussion of the subject. The final chapter on magnetic films of nickel-iron is obviously included because of their possible application to the computer store problem but includes a thorough discussion of their physics and measurements.

The first article in the second volume, structural disorder phenomena in thin metal films, is a very good survey of the formation and structure of thin films. It discusses the formation of nuclei, the effect of deposition conditions on nucleus size and the various consequences of nucleation on film properties. This is probably the best and is undoubtedly the most important article in these two volumes. The article on electron beam interaction deals generally with the interaction of electrons with solids and is perhaps not as useful to the film physicist as it might have been.

Weimer's article on the thin film transistor is most detailed and might lead one to suppose that from its study, the reader could proceed to make a T.F.T. However, many have tried, but few other than Weimer have been successful, and one may doubt even his optimism on the future of the T.F.T. noted at the end of the article.

Heavens' article on the measurement of the optical constants of thin films is the only British contribution and is thorough and well balanced. Two further optical articles cover the theory and design of anti-reflection coatings, and the currently important subject of solar absorptance of films.

The final chapter on thin film components and circuits is generally a very good survey of the field of film micro-electronics including comments on all the main component materials. On such topics involving much new work and where different workers' techniques and results differ in fine detail, it is easy to take issue with many detailed points, but this does not detract from an excellent article.

These volumes form a worthy start to what will, over the years, be an excellent historical survey of thin film physics. The standard of production is very high, as one has come to expect from the U.S. technical publishers.

F. M. Foley

Paint Technology Manuals. Part Four. **The Application of Surface Coatings.** Oil and Colour Chemists' Association. Pp. xiii + 345. Chapman and Hall: London. Price 35s.

This is the fourth in the series of Paint Technology Manuals prepared by specialists for the Oil and Colour Chemists' Association.

This volume on application of surface coatings explains the basic principles of finishing the more common substrates found in industry and gives the reasons for the selection of the particular pretreatment, coating system and the method of applying it.

The subjects covered include decorative painting, industrial metalware, cars, constructional steel, ships, woodwork, leather, plastics, electrical equipment and paper.

Each chapter is written by a specialist author and in most cases the treatment is quite comprehensive. As an example, the chapter on industrial metalware covers ferrous metals, aluminium alloys, tinplate and copper and its alloys. Ferrous metals are broken down into a consideration of the types of corrosion which may occur, methods of cleaning, descaling, pretreatment and types of paint. Then follows the factors governing the choice of paint for bicycles, rail coaches, agricultural machines, drums, metal signs, office furniture and so on. The

chapter concludes with a most useful section on defects in the final paint coating.

This amount of detail is not given in each chapter, but considering the diversity of subjects and the natural differences in style of separate authors, the editors have achieved a very good balance. There is inevitably some repetition, but provided the reader regards each chapter as complete in itself, this does not irritate.

Proof reading has been carried out most thoroughly and there are remarkably few errors. The most obvious one is the unfortunate siting of Figures 40 and 41 in the section on industrial woodwork. They should obviously appear opposite page 203 or 204 in the marine finishes section.

In all, this is an admirable piece of work and up to the standard of the three earlier volumes. The text is clear, accurate and practical, with the needs of the student and the practical man in industry both in mind. It is good value for 35s. and should find a place on the bookshelf of anyone concerned with or even merely interested in surface coatings. **J. C. Kingcome**

Problems in Inorganic Chemistry. By B. J. Aylett and B. C. Smith. Pp. xii + 154. London English Universities Press. 1965. Price 21s.

I remember with horror endless calculations on equivalents, the law of multiple proportions, rates of reaction, and so on. Once one had learned to look up the right logarithms, that was that. How different is the approach of the present book. The reader is made to feel that he is actually participating in research projects. The very full answers often give references to the sources, and remarks like "These values show the risks of drawing structural conclusions from incomplete magnetic data" give just the right atmosphere. One is not merely trying to verify conclusions, but to dig them out in the manner of a detective story.

If I had been taught out of this book, I might well have plumped for chemistry instead of physics! I recommend it warmly. **H. N. V. Temperley**

A Simple Approach to Electronic Computers. 2nd Edition. By E. H. W. Hersee. Pp. xi + 261. Glasgow, Blackie & Son Ltd. 1966. Price 25s. (Bound), 15s. (Paper Back).

This is the second edition of a book first published seven years ago. In order to bring the monograph up to date two chapters have been added. One of these is devoted to Incremental Computers, the other to a discussion of a miscellany of digital topics, mainly philosophical. This carries the broad heading of "Some elaborations, simplifications and limitations." This chapter is not a very penetrating one and attempts to introduce, with only limited success, the concept of Computers and Thought.

The additional chapter on Incremental Computers provides a useful link between the digital and analogue sections: The Incremental Computer may be described as one which does its basic calculations in digital form but which relies on an organisation which closely resembles that of an analogue machine.

Incremental Computers are explained with much clarity. But a point which is not clearly made is that they are best applied when the problem has a large trigonometrical content and justifies exploiting their special features in a purpose-built system, e.g. for ballistics or navigation.

However, taking a broad view of the book, one is led to conclude that this is a well-written treatise of a subject much written about. It compares more than favourably with other monographs which have had the same aim—to provide a useful introduction to more advanced text-books. In the same series there are other volumes dealing with digital and analogue techniques separately. In this volume there are two (nay, three) subjects covered adequately for the price of one. This is perhaps not a very logical recommendation and so it is only fair to conclude with a positive commendation that the subjects in this monograph are presented lucidly and coherently and that it provides a competent introduction to a subject for a reader who wants to know about computers generally but who is not a computing practitioner.

G. Harries

Examples in Electrical Installation Work. By G. Watkins. Pp. 153. London. Blackie and Son Ltd. 1965. Price 11s. 6d.

This book has been written primarily for students preparing for the City and Guilds of London Institute Electrical Installation Examinations B and C and is, as is obvious from the title, a collection of simple worked examples at the appropriate level. In addition, exercises, with numerical answers only, are provided at the end of each chapter.

Little comment can be made upon the text of such a book, since this is virtually non-existent, so the chapter headings, which are self-explanatory, will be quoted to give an idea of the scope of the treatment: Resistance, Power, Energy and Work; Space and Water Heating; Batteries and Cells; Tariffs; Meters; d.c. Generators and Motors; Magnetism and Induction; Illumination; Capacitors, Electrostatics and Insulation Resistance; a.c. and d.c. Distribution; Single-Phase a.c. Series and Parallel Circuits; Single-Phase Transformers; Power Factor; Single- and Three-Phase Motors.

No attempt has been made by the present reviewer to check every calculation given in the book, but those selected for checking were correct (unlike some answers in a book of examples from another publisher). Presumably, the coverage reflects accurately that of the syllabus of the above-mentioned examination and this is surprisingly wide for such a subject, since one would expect such items as lighting and heating to be specified by an architect or engineer for a particular building and those responsible for installation would merely be expected to adhere to the specification. However, if this knowledge is required of the examination candidate, this book should give him an idea of the methods required to perform the relevant calculations.

R. J. Male

Unified Circuit Theory in Electronics and Engineering Analysis. By J. W. Head and C. G. Mayo. Pp. 174. London. Iliffe Books Ltd. 1965. Price 42s.

This book is devoted to backing up the authors' contention that Heaviside's operational calculus provides a tool for the solution of non-steady state problems, as useful to the engineer as Laplace transforms and symbolic calculus, whilst being easier to use. The first part of the book caters for the engineer who wishes to solve practical problems (most do!). The second part is devoted to more theoretical considerations and also deals with the analysis of linear distributed circuits.

The text, after an introductory chapter, commences with a reassurance to the reader, by treating elementary arithmetic as an operational calculus. It then goes on to consider reversible operational calculus and the solution of simple circuit problems. Partial fractions and Heaviside Shift theorems are next covered and a short historical survey of the subject, together with Laplace

transforms and symbolic calculus follows. The book then gets down to business and deals with the mathematical tools and processes required, such as step and impulse functions and convergence. The uses of operational calculus, with sinusoidal inputs, arbitrary input and feedback are next considered. A comparison of operational calculus with symbolic and transform calculus is given, in order that the authors may make their point, and the book proper closes with two chapters upon synthesis by means of vectors and coherence and continuity. A further chapter provides a summary of the results obtained in the book. Five appendices, including a short introduction to Matrices, are included.

Many authors, when attempting proselytisation, tend to indulge in the practice of wrapping up their subject in esoteric phraseology. This accusation cannot be levelled at the authors of this book. Their text is noteworthy for its clarity and should enable the reader to gain a good grasp of the essentials of the subject. It is unusual for a book of this nature to make entertaining reading, but this one does approach that desirable state, even being enlivened when referring to the boundary of a Fourier integral, with the statement " Cursed is he that removeth his neighbour's landmark " (Deuteronomy XXVII, 17). One is tempted to add, in the case of the authors, " Blessed be he that helps his neighbour who is not in a steady state."

R. J. Male

CO_2 Shielded Consumable Electrode Arc Welding. By A. A. Smith. Pp. 135. Cambridge; British Welding Research Association. 1965. Price 45s.

The preparation of a second edition of " Smith's CO_2" marks the continued growth of this important electric-arc welding process in which the weld region is shielded by an almost inert gas. From the excellent contents list one finds that in the first seven chapters Mr. Smith describes the process and admits its limitations, and then reviews the equipment, materials and techniques used, while the remaining four chapters are devoted to the successes and problems of application. There is a brief index. The book is lavishly illustrated throughout with line diagrams and photographs of the high standard which comes to be expected of B.W.R.A. Three trivial printing errors were found.

The technical content of most of the book is excellent. Reading it through straight from start to finish a lot of repetition is noticed, but in a work of reference this is unavoidable. The subject matter is, with only a few lapses, very clearly expressed. In a welding context only a purist would object to the concept of electrons being evaporated at the cathode and condensed at the anode of the electric arc. Practical men will gladly follow Mr. Smith through his accounts of mechanical and electrical stability in and around arcs. However, the treatment of metallurgical points in Chapter VII gives cause for concern. Refining and tempering are not synonymous. And where is Figure 42(c) ? Reading this chapter one suspects Another Hand, which has not paid sufficient attention to textual and editorial accuracy.

A notable omission from Chapter X, Special Processes, is the pulsed-arc process. Is the omission deliberate ? Is there a companion volume being prepared ? One hopes there is. If it is only half as good and as timely as the present book, it will be an outstanding work of exposition and reference for many years to come. For the welding specialist, be he in research development or production, " Smith's CO_2" is a must.

A. P. Bennett

Theory of Machines (For Higher National Certificate Courses). By P. J. Howard. MacDonald & Co. (Publishers) Ltd. 1965. Price 40s.

This book, primarily for students following the subject leading to Higher National Certificates, has been written by the Principal of a technical college. It is stated to be useful for candidates to the Part II examinations of the major Institutions as well.

The syllabuses for this subject at technical colleges vary from area to area so the would-be buyer would need to know whether the book meets the requirements of the area. It can be said, as a guide, that the syllabus for the Part II Examination of the Institution of Mechanical Engineers has been covered with the exception of Control Systems. This subject has only recently been introduced into the syllabus and an additional chapter on this subject would have been well worthwhile. There is also the possibility that this subject might be renamed " Mechanics of Machines " in the technical colleges as has been so with the Mechanical Engineers. In view of the above the publication of this book could, with advantages, have been delayed 12 months.

In general the book is well written and covers the subjects of the old syllabus in a most lucid manner with an abundance of descriptive diagrams. The author being obviously an experienced and practical lecturer has made good use of his worked examples to help the Student. The recommendation to carry units throughout the calculations, to assist accuracy, has been followed with care proving the wisdom of such a policy and is endorsed by the writer.

A book well worth buying for anyone interested in this subject with the proviso mentioned.

R. J. Richardson

Electronic Data Processing Systems—A Self-Instructional Programmed Manual. By Leeland R. O'Neal. Prentice-Hall International. Pp xi + 409. Price 60s.

This type of book has, over the last year or two, become increasingly popular with the computer laity. It provides an interlaced series of information and response steps, and is designed to allow the student to learn the relevant material at his own rate with adequate reinforcement stages.

In this reviewer's opinion much of the theoretically possible benefit obtainable from this type of book is lost in the unfortunate format. The desired responses to questions are printed in capitals underneath a row of five asterisks (to separate answer from question), and it is practically impossible to turn from page to page without seeing the answers. The layout of the sequences makes the material eminently suitable for adaptation to a teaching machine film strip, but it is not really suitable for book form presentation. Another criticism of the technical presentation is that in the later sections the next page to be read depends upon the particular response given to a question, for example, " If answer (a) is selected turn to page 173, if answer (b) is selected turn to page 345, etc.". If this is to be done then it is essential that printing errors in the page numbers should not occur. This unfortunately, is not the case.

The information content of the book is quite standard material and has an obvious leaning towards I.B.M. system computers. This is not unreasonable since the author states that the book has been prepared with I.B.M's Customer Engineering Training Centre at Poughkeepsie in mind.

An expensive book at 60s. This reviewer disliked the form of presentation, and felt that most of the material would be provided by a computer firm to a new-entry employee on initiation course.

R. W. Sudweeks

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Illustrations are in most cases a desirable addition. Photographs should be of good quality, glossy, unmounted, and preferably between two and three times the size of the required final picture. Graphs and line drawings should be made on a similar large scale, with bold lines to permit reduction in block making.

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